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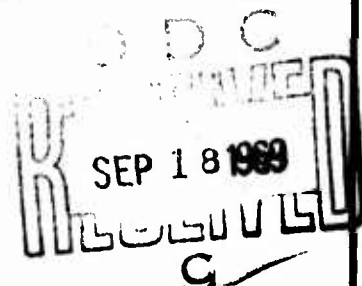
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DEVELOPMENT OF MAU-91/B FIN ASSEMBLY

T. W. Alles
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General American Research Division
General American Transportation Corporation

TECHNICAL REPORT AFATL-TR-68-47

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EGLIN AIR FORCE BASE, FLORIDA

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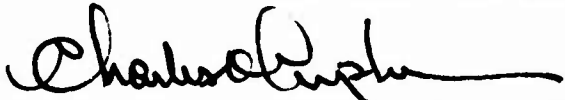
T. W. Alles
J. S. Islinger

FOREWORD

This report was prepared by the General American Research Division of General American Transportation Corporation, 7449 N. Natchez Avenue, Niles, Illinois, as partial fulfillment of the work required under Contract No. AF 08(635)-4612 for the design, development, fabrication and test of prototype speed brake decelerators for the M117 bomb. The program, designated as GARD Project 1267,was under the technical supervision of the Air Force Armament Laboratory (ATWB), Eglin Air Force Base, with Major L. G. Reilly, Capt. J. Morris, Capt. D. G. Jones, Capt. P. W. Elder, and Capt. R. Smith, successively, acting as Project Engineers. Work on the contract was initiated in August 1964 and concluded in November 1967.

GARD personnel who materially contributed to the technical success of this program include R. E. Stern (Director of Ordnance Systems), T. W. Alles (Project Engineer), F. Bloedow, R. Golbach, F. Kurz, W. Laski, D. Parker, J. Poczatek, B. Rau, and R. Vaitys.

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This technical report has been reviewed and is approved.

CHARLES K. ARPKE, Lt Colonel, USAF
Acting Chief, Weapons Division

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ABSTRACT

This program was concerned with the design, development, fabrication, and testing of a prototype speed brake decelerator that gives the M117, 750 pound bomb a low level delivery capability. The requirement for the decelerator became urgent, as a result of the conflict in South East Asia, and the program was expanded to include development of preliminary production tooling and fabrication of production type decelerators to qualify the unit for aircraft. In addition, a shipping and storage container was developed and tested and a complete set of specifications was prepared to enable the Air Force to procure the decelerator in large quantities. The decelerator was designated the MAU-91/B Fin Assembly and was put into production by GARD concurrent with this research and development program. The decelerator consists of four extendible fin-drag plates connected through links to a forward support, which attaches to the bomb. The fin-drag plates are retained in the closed position by a release band and latch assembly, and the latch is held closed by an arming pin. When the arming pin is withdrawn, the fin-drag plates are snapped open by leaf springs and fully opened by the action of the aerodynamic drag. This program permitted development support for the parallel production program by providing: (1) fixes as required by production testing, (2) design changes as indicated by production problems and processes, and (3) investigation of improved decelerator designs to reduce cost. A delayed opening device was designed to enable the decelerator to be carried and deployed from the bomb bay of bomber aircraft. A sizeable quantity of delay devices were fabricated and successfully tested on B52 aircraft. In addition, a guide assembly (MAU-105/B) was developed and fabricated for use with the MAU-91/B Fin Assembly on the F100 aircraft.

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SECTION I

INTRODUCTION

1.1 Program Objectives

The original objective of this program was the design, development, fabrication and testing of a prototype speed brake decelerator that would give the M117 bomb a low level delivery capability (Figure 1). As the program progressed, and the requirement for the decelerator became more urgent as a result of the conflict in Southeast Asia (SEA), the contract was modified and the objectives and scope of the program were increased. The objectives of the program were expanded to include the development of preliminary production tools (forging dies, etc.), fabrication and production of a sufficient number of retarders to qualify the unit for aircraft, the development and testing of a shipping crate, and the writing of a complete set of specifications to enable the Air Force to procure the developed unit in large quantities.

During this time, the need for the decelerator for use in SEA became extremely urgent, and before the decelerator had been completely developed and tested GARD received a production contract which called for the setting up of a production plant, the development of full production tooling, and the fabrication of a significant number of decelerators. Concurrent with the production contract, the R&D program was further extended, as a parallel development program, to provide fixes as required by the qualification testing, provide design changes as indicated by production problems and processes, and to investigate improved designs of the decelerator to reduce the cost. A further modification to this program was received which required the design and fabrication of a number of delayed opening devices to enable the decelerator to be carried internally and deployed from the bomb bay of bomber aircraft. This device was to be used on the MAU-91/B and the MARK 15 fin assemblies, interchangeably. The final modification to the contract required the further development of the delayed opening device, the delivery of 1000 delayed opening devices for test with the B52 aircraft, and the development and fabrication of the MAU-105/B Guide Assembly (used on certain stations of the F100 aircraft with the MAU-91/B Fin Assembly).

1.2 Summary of Contractual Changes

Table I summarizes the contractual changes that occurred during the program and outlines the effective time period of the contract modifications and the changes in objective and scope.

1.3 Summary of the Program

1.3.1 Program Approach

The purchase request and the original R&D specification outlined a decelerator based upon the MARK 15 (SNAKEYE) fins developed by the Navy for use with the MARK 82, 500 pound bomb. However, early in the program it became apparent that because of the increased performance requirements

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Figure 1 M117 Bomb/MAU-91/B Decelerator Deployment Sequence

TABLE I. SUMMARY OF CONTRACT AND MODIFICATIONS SCOPE AND OBJECTIVES

Contract and Modification	Effective Time Period	Objective and Scope	Remarks
Original Contract	August 1964 - March 1965	Design, develop and deliver 5 prototype retarders	
Mod. 1	April 1965 - February 1966	Further develop retarder and packaging. Deliver 185 retarders and 120 packages. Procure production forging tools.	Required 77 hand fabricated units and 108 units with forged components made from production forging tools.
Mod. 2	No Change	No Change	Changed name on contract from MRD to GARD.
Mod. 3	May 166 - October 1966	Revised number of retarders from 108 to 158 and to refine retarder design.	Increased forged units to include 50 modified retarders.
Mod. 4	October 1966 - January 1967	Develop and fabricate time delay devices. Reduced number of forged retarders from 158 back to 108, and added 700 time delay devices.	Required development and delivery of 700 pyro-technic time delay devices for use on retarders in bomber aircraft.
Mod. 5	January 1967 - April 1967	Develop time delay for use with MAU-91/B and Mark 15 fins based on mechanical approach.	Wanted a mechanical device for achieving safe fin deployment from bombbay.
Mod. 6	June 1967 - September 1967	Fabricate 1000 mechanical delays and develop and deliver 200 arming cable guide plates.	Fabricate delays developed under Mod. 5 and develop fix for deployment problem F-100 A/C using MAU-91/B fins.

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for the MAU-91/B decelerator and the severe weight limitations called for in the R&D specifications, a radical departure from the SNAKEYE design would be necessary. In the early stages of the program, the major departure from the SNAKEYE design occurred in the fin-drag plate design and in the technique used to attach the fin assembly to the bomb. Later, a more effective energy absorbing device was developed, a change in the basic mode of opening of the decelerator fins was incorporated, and the development of a new technique for releasing the fins for deployment was completed.

In the initial design studies and stress work, a C_D was used for the fin-drag plate based upon the C_D determined for SNAKEYE fins during its development program and wind tunnel testing. It was expected wind tunnel tests would be conducted on a model of the MAU-91/B retarder; however, the structural tests of the unit were successful and indicated substantial margins of safety and the Air Force decided to go directly to flight testing and to hold the wind tunnel work in abeyance until later in the program. This decision saved a significant amount of time in the development, and, as the testing of the units continued, it became apparent that a wind tunnel program was not necessary.

Theodolite readings taken during some of the air drops yielded retarded bomb trajectories, and the trajectories were used to derive C_D vs Mach number for the MAU-91/B fin (see Section 5.3). The C_D derived from the actual test drop was somewhat less than the C_D used in the stress and design calculations, and it appeared that the design was slightly conservative. This conservative design enabled the unit to withstand a more severe deployment environment, in the form of a severe pitch down of the bomb during ejection than had been anticipated.

After the initial testing, and Amendment 1 to the program, the technique of hand fabricating was used for a limited number of items of a specific design, normally 4 to 8, and dropping them before fabricating additional units. Then using the results of these drop tests any required modifications were incorporated into the next lot of 4 to 8 units. This technique was very successful, and early in the program it was possible to fix the design of the primary components, such as the fin-drag plate and the forged items. This enabled procurement of the forging dies with a high degree of confidence that they would not have to be changed. In fact, the original forging dies procured for the development program were later used with only very minor modification in the production program. This technique resulted in a considerable saving in lead time during the early stages of production.

Another significant technique used by the Air Force during this program was the continuation of the development effort concurrently with the initial production. Having the development program in effect during the initial stages of production and during the initial qualification testing, enabled the test program to be supported by having field representatives at Eglin, and enabled very quick reaction to problems indicated during the qualification testing. Probably the most significant problem that occurred during the testing, was the need for a new release technique that would give satisfactory reliability during the

high speed deployment. The failure of the deployment technique, taken from the MARK 15 fins and used on MAU-91/B fins, at high delivery speeds resulted in an unacceptable number of low drag drops, and a complete new system was developed and incorporated into the production items during the initial production run.

Later in the program, as a requirement for dropping the M117/MAU-91/B from a bomb bay developed, it was possible to immediately begin development of a delay device. The first device was based on a pyrotechnic element to delay deployment. The second device was mechanical and was developed to reduce cost, to improve reliability and to assure that fin deployment occurred at the same point after every release. Both devices were developed on a quick reaction basis.

1.3.2 Development Problem Areas

While many problem areas were encountered during the decelerator development program, the most significant were: (1) the severe weight limitations originally specified, (2) the need to develop a new energy absorber which could absorb the energy generated by the high delivery speeds and still maintain an acceptable load input into the structural components, (3) the unexpected pitchdown of the units which occurred during deployment (see Figure 2) from the various stations on the F105 and F100 aircraft, which imposed an extremely severe loading upon the structural components, and (4) the development of a new arming system for high speed deployment. The problems created in these areas were all resolved during the program.

Figure 2 Pitch Down and Subsequent Failure During
Decelerator Deployment

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SECTION II

PRELIMINARY DESIGN OF DECELERATOR

The original decelerator concept was based on the MARK 15 fin (SNAKEYE). The concept consisted of four extendible fin-drag plates connected to a support which attached to the bomb body, plus the necessary mechanical linkages and energy absorbing devices required to provide safe and reliable operation. The fin-drag plates were retained in the closed (or low drag) position by a release band and latch assembly, and the latch held closed by an arming pin. When the arming pin was withdrawn, the fin-drag plates were snapped open by leaf springs and fully opened by the aerodynamic drag load acting on them. The energy of the deploying speed brakes would be absorbed by plastic deformation of an energy absorbing device and the fin-drag plates stopped approximately perpendicular to the airstream, affording maximum drag area. The retarder would be attached to the M117 bomb body by means of a quick connect-disconnect joint.

2.1 Decelerator Requirements

The original requirements for the bomb retarder were:

1. A total area of the fin-drag plates of fifteen square feet when deployed perpendicular to the airstream.

2. A length of the decelerator device not exceeding 38.5 inches and a width, when in the low drag configuration, not protruding beyond the cylindrical envelope formed by the fins and bomb body of the standard M117 bomb.

3. An allowable weight of 90 pounds for the speed brake decelerator device.

4. A decelerator design compatible with both nose and tail fuzing systems. Provision of sufficient space for installation of a tail fuzing system, comprising a tail fuze, drive shaft and arming mechanism.

5. Capability for external carriage of the speed brake on aircraft at speeds up to Mach 0.95 and at altitudes up to 50,000 feet and deployment at speeds of 600 knots and at altitudes down to 50 feet above the terrain.

6. Aerodynamic stability of the M117 bomb with the decelerator in both high and low drag modes at speeds up to Mach 0.95 and altitudes as high as 25,000 feet.

7. A mean failure rate of the fully developed decelerator no greater than one per one thousand weapons dropped, in accordance with MIL-R-27542.*

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* MIL-R-27542 was superseded by MIL-STD-785, 30 June 1965.

8. A mean time to repair (MTTR) the fully developed decelerator of 15 minutes in accordance with MIL-M-26512C.** Design of the prototype decelerator so as to incorporate maximum accessibility.

9. Design of the prototype decelerator device cognizant of the environmental test requirements of MIL-STD-810.

2.2 Design Problems

The two major problems inherent in the design and development of the bomb retarder were:

1. Development of an efficient decelerator, capable of economical production, within the required weight limitation of 90 pounds.

2. Development of a successful energy absorption system capable of absorbing the tremendous opening force, permitting a smooth fin-drag plate opening action while minimizing the forces experienced in various decelerator structural components.

2.2.1 Design for Minimum Weight

The first approach to a design of the M117 bomb retarder was an attempt to scale up the decelerator used in the SNAKEYE series of 250 and 500 pound bombs. This resulted in a retarder design which greatly exceeded the original 90 pound weight limitation; consequently, this approach was abandoned very early in the program. A study of the various components required in the decelerator assembly indicated that the most substantial weight savings could be obtained by a redesign of the fin-drag plates. A study was made in which a number of fin-drag plate configurations and materials were investigated.

Many materials were considered including some extremely high strength alloy steels, high quality aluminum and magnesium alloys and molded glass reinforced plastics. Concurrent with the materials investigation, various air brake configurations and cross sections were considered utilizing a number of fabrication techniques. As a result of these studies, an aluminum alloy, 7075-T6, was selected for the fin material. Two general approaches to the fin-drag plate design were selected: (1) a fin of one piece construction, and (2) a fin fabricated from several pieces. A study of fabrication techniques required for production of the two fin types revealed that the one piece fin (Figure 3) would require the greater amount of tooling, while a two piece fin (Figure 4) would present joining problems, i.e., welding 7075-T6 is not recommended, riveting would be inefficient from a weight standpoint and also uneconomical. The one piece fin appeared to possess more advantages than did the two piece fin. Therefore, the one piece fin design was selected for further development and static testing.

** MIL-M-26512C was superseded by MIL-STD-470, 21 March 1966.

Figure 3 One Piece Fin-Drag Plate

Figure 4 Two Piece Fin-Drag Plate

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A great deal of effort was expended in developing the optimum fin-drag plate design. This required optimizing the cross-sectional shape to match the geometrical requirements to obtain the optimum combination of material thickness and fin shape for minimum weight and adequate strength. At least 15 designs were considered and analyzed, with computer programs, before the final design was achieved. The primary problem in the fin-drag plates was getting a fin design that would take the extreme bending loads imposed during deceleration of the fin as it approached the full open position. This problem could not be solved without considering the other problems associated with the design. It would have been desirable to move the attachment point for the links farther toward the tip of the fin which would have reduced the bending loads; however, the geometry of the unit did not permit this. The geometry of the fin assembly, the diameter of the support tube, etc., required a fixed length for the links and limited the location of the attachment point.

Weight reduction of the other decelerator components was the subject of additional study. The study indicated that component weight could be reduced by reducing the loads transmitted to the components by the action of the energy absorber during the fin opening. The most direct way to accomplish this was to increase the distance through which the absorber acts, which in turn reduces the opening force. The maximum stroke is limited by the decelerator geometry and by the selection of the point during the opening when buffing action starts. The absorber stroke was increased primarily by starting the buffing action at a point where the fins reach an angle of 50 degrees during opening instead of an originally selected angle of 65 degrees. An analysis was made of the expected loads under the new loading conditions. The calculated stresses on the fins and the bomb attachment ring appeared to be marginal and indicated the need for an increase in material thickness with a corresponding weight increase. Therefore, additional ways to increase the absorber stroke were considered. Details of the absorber development are given in Section 2.2.2.

As the fin design problem was resolved and a longer stroke on the energy absorber was considered feasible, the next most promising area for weight reduction appeared to be the support tube. It was possible to estimate the loads which the fins transmitted to the support tube, which were primarily due to the steady state drag of the fins and the bending loads imposed by yaw of the bomb. Using these loads, a computer program was developed in which the wall thickness and the diameter and hence, the weight, of the tube could be varied to obtain a tube having the optimum wall thickness and tube diameter for minimum weight. These studies enabled selection of the optimum wall thickness and tube diameter for the given load conditions.

This same philosophy of obtaining an optimum design, which would give a minimum weight and the required strength, was followed in the other major components. For this reason, it was decided to use forged components made of 7075-T6 aluminum. Using forgings, it was possible to obtain lower weight for the specified design loads than could have been obtained with extrusions. Also, it was found, when pricing for production, that the forgings were cheaper than extrusions for these components. These components were the links, the collar, the clevis, and the link supports. In the interest of weight reduction, all major components were fabricated of 7075-T6 aluminum alloy.

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2.2.2 Energy Absorber Development

The initial energy absorber concept consisted of two metal tubes of the same diameter and thickness arranged in **tandem**. At the point of contact, one tube had a swaged mouth, while the other had a thickened cross section. During fin opening the tubes were to absorb the energy by a swaging action -- one tube was to swage over the entire length of the other. When it became necessary to increase the absorber stroke in order to reduce loads transmitted to other decelerator components, the number of swaging tubes was increased from two to three (Figure 5). This increased the length of the buffer stroke from 8 to 12 inches.

Another energy absorber concept consisted of an aluminum honeycomb tube (Tubecore*). A number of Tubecore configurations were subject to dynamic testing to determine the effect of dynamic loading on the performance and for comparative evaluation of each configuration. The configurations (comprising honeycomb tube overwrapped with fiberglass tape) tested are shown in Figures 6 and 7. Prior to the tests it was estimated that static crush strength of the order of 3000 psi would be required of the absorbers. The Tubecore specimens were configured to permit a 14 inch stroke during the buffing action. Under dynamic conditions, through such a stroke, the absorber could experience loads of the order of 4000 to 4500 psi.

Two series of tests were conducted on the Tubecore specimens shown in Figure 7. The first series of tests were run at a load application rate of 55 fps (approximately one-half the maximum expected velocity). The second series was run at a rate of 110 fps (the maximum velocity). The tests indicated that configuration D was the most promising; it underwent slightly more than 14 inches of crushing at the high velocity and approximately 7.5 inches of crushing at the low velocity.

Additional type D absorbers were tested with added layers of fiberglass tape to prevent curling, and with end caps added to further confine the Tubecore during crushing. These absorbers gave satisfactory test results for the predicted loads and were supplied on the first five prototype decelerators. However, it was believed that a configuration offering greater crushing resistance and having greater energy absorbing capability was necessary to give an added margin of safety in the event that the actual loads were larger than the predicted loads. However, the loads imposed on the decelerator assembly are proportional to the energy absorber crush strength. Therefore, a compromise between absorber crush strength and acceptable decelerator loads was essential to minimize weight.

Dynamic testing was continued using absorbers have various static crush strengths. As a result of the additional testing, an absorber configuration was selected having a slightly higher crush strength and energy absorbing capability than that supplied on the first five prototypes. The higher strength absorber was utilized in the first lot of eight units fabricated under Modification 1 to the contract.
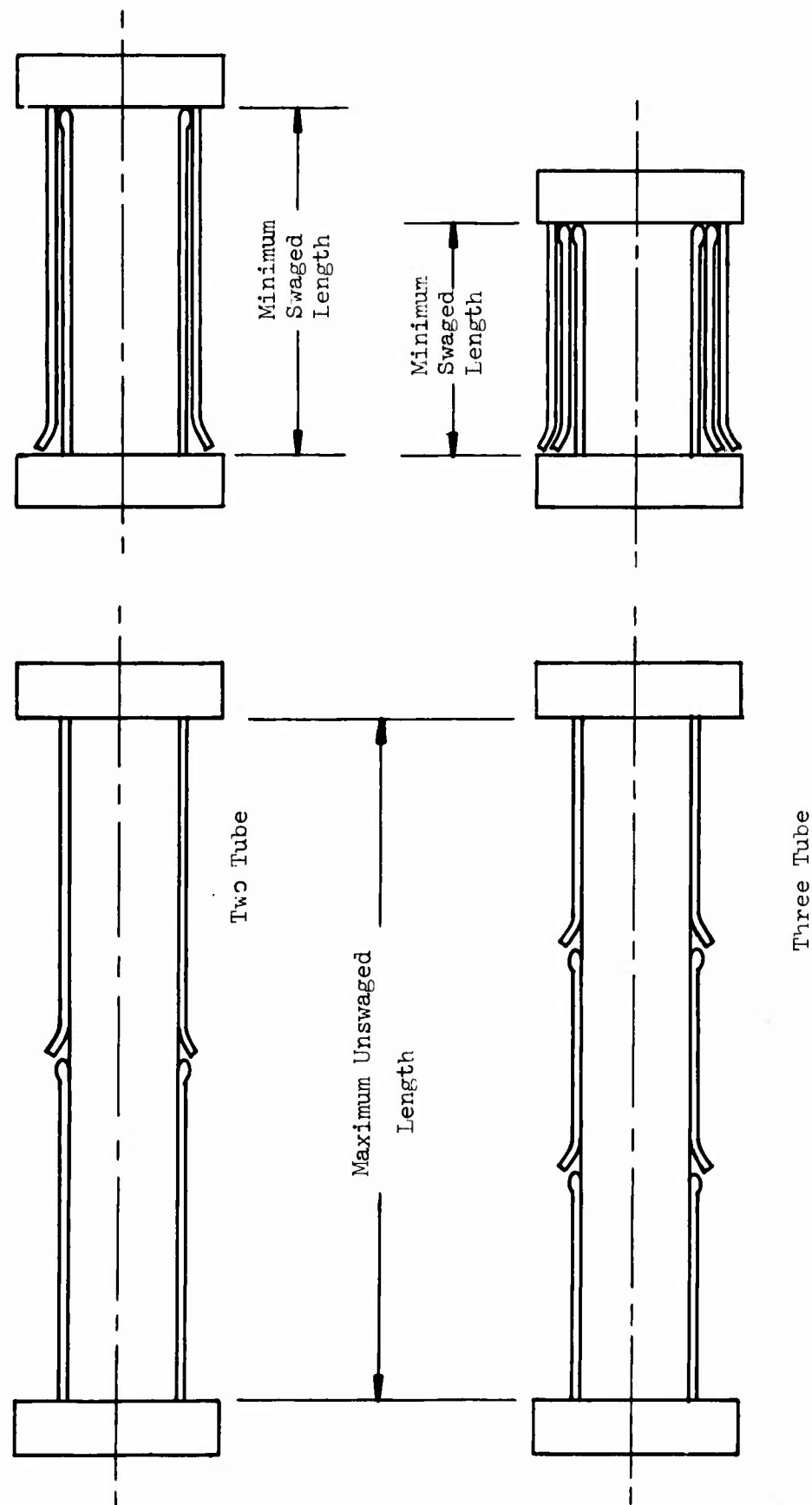
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* Hexcel Corporation.

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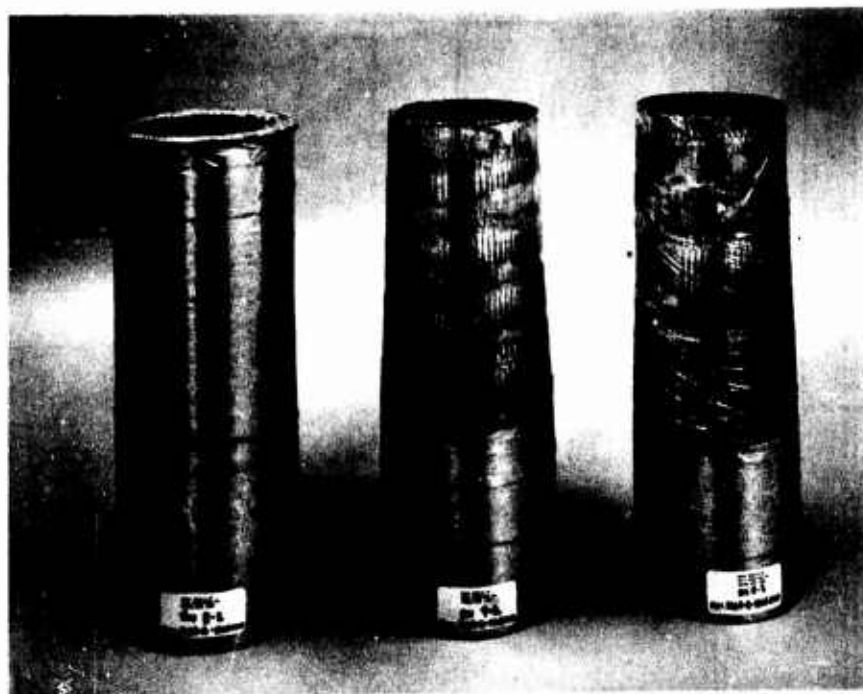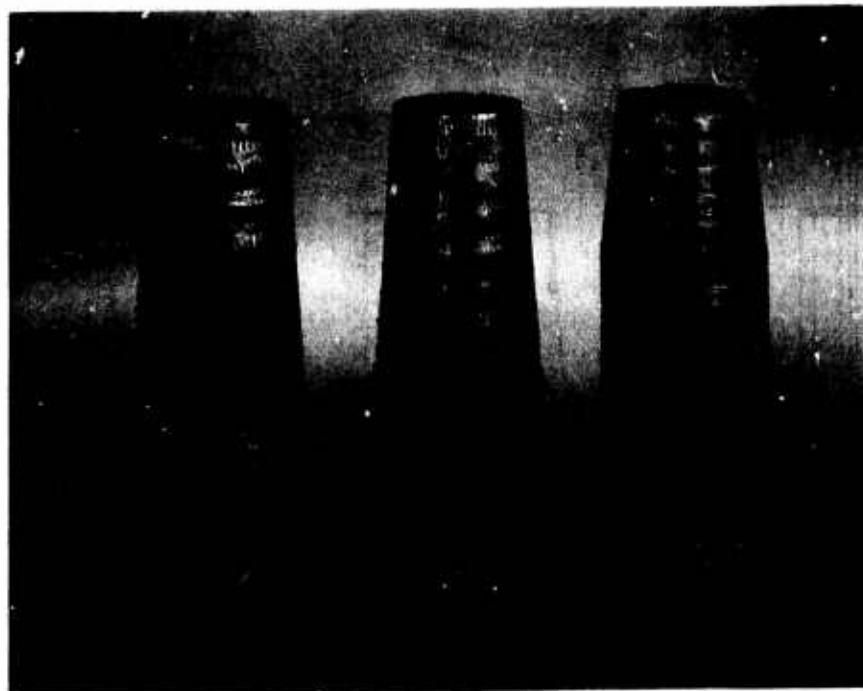Figure 5   Comparison of Two and Three Tube Buffer Configuration

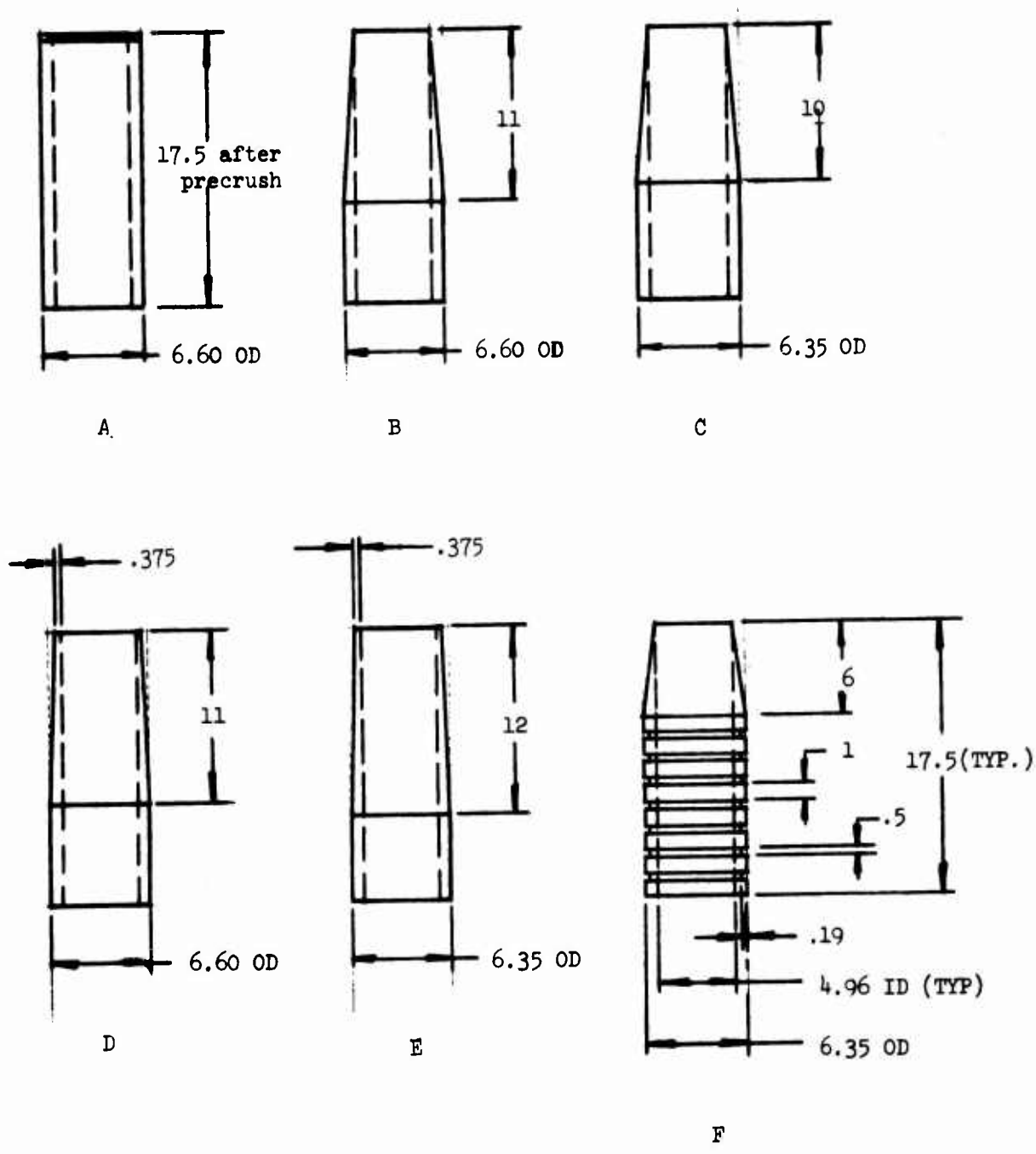Figure 6   Tube Core Buffers for the Dynamic Test

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Figure 7 Configurations of the Buffer Test Items

For the next lot of eight decelerators two types of honeycomb energy absorbers were employed. Both types had significantly increased energy absorbing capabilities over the previous absorbers. Four of the absorbers were of the same configuration as previously; however, they had significantly increased static crush resistance for increased energy absorbing capabilities. The other four absorbers were three inches longer (increased from 17-1/2 to 20-1/2 inches) with the same static crush strength as the previous absorbers. Drop tests of decelerators containing these absorbers indicated good performance. Therefore, the next 16 energy absorbers had very similar configurations.

Some of the next 16 absorbers were used and tested in decelerators having modified collars (steel sleeve inserts). With reduced friction between collar and support tube, several absorbers bottomed out, because of insufficient capacity, and caused decelerator failure. The remaining absorbers were replaced with ones having higher energy absorbing capacity.

On the basis of additional drop tests, the next 25 absorbers were of two more types: the first was 21-1/2 inches long and had a static crush strength in the range of 46,000 to 50,000 pounds, and the second was 18-1/2 inches long and had a static crush strength in the range of 50,000 to 54,000 pounds. The selection of the short absorber having the higher crush strength was predicted upon obtaining roughly the same energy absorbent capacity for both short and long units. It was believed that the shorter absorber would give a better fin-drag plate deployment angle at lower air speeds than would the longer absorber. The drop tests were generally successful with both types of absorbers working equally well.

A significant innovation reversing the opening mechanics of the decelerator reduced opening velocity and, hence, loading in the fins and the components including the absorber. The required static crush strength for absorbers in decelerators with reversed opening was estimated to be 20,000 to 22,000 pounds which significantly reduced the inertial loads on the fin-drag plates. Therefore, absorbers with this crush strength were used in subsequent tests of 20 decelerators. The results were satisfactory, and this configuration of the absorber was used in subsequent developmental and production decelerators.

As a possible backup for the aluminum honeycomb absorber, experimentation was made with a different type of material. The material investigated was an annealed steel tube. In absorbing energy, the tube was first expanded at one end and then split into eight segments with each segment then coiled simultaneously. The amount of energy absorbed could be varied by variation of such parameters as type and thickness of material, amount of expansion, degree of curling prior to splitting, and radius of curl. The approach has two basic advantages: the first is its simplicity and relative cheapness, and the second is the fact that the curling permits the curled material to be stored in a small volume, and, therefore, permits a relatively long stroke. A tube which was split and curled and the collar used to perform the expansion and curling are shown in Figure 8. The sequence of a tube being coiled during static tests is shown in Figure 9.
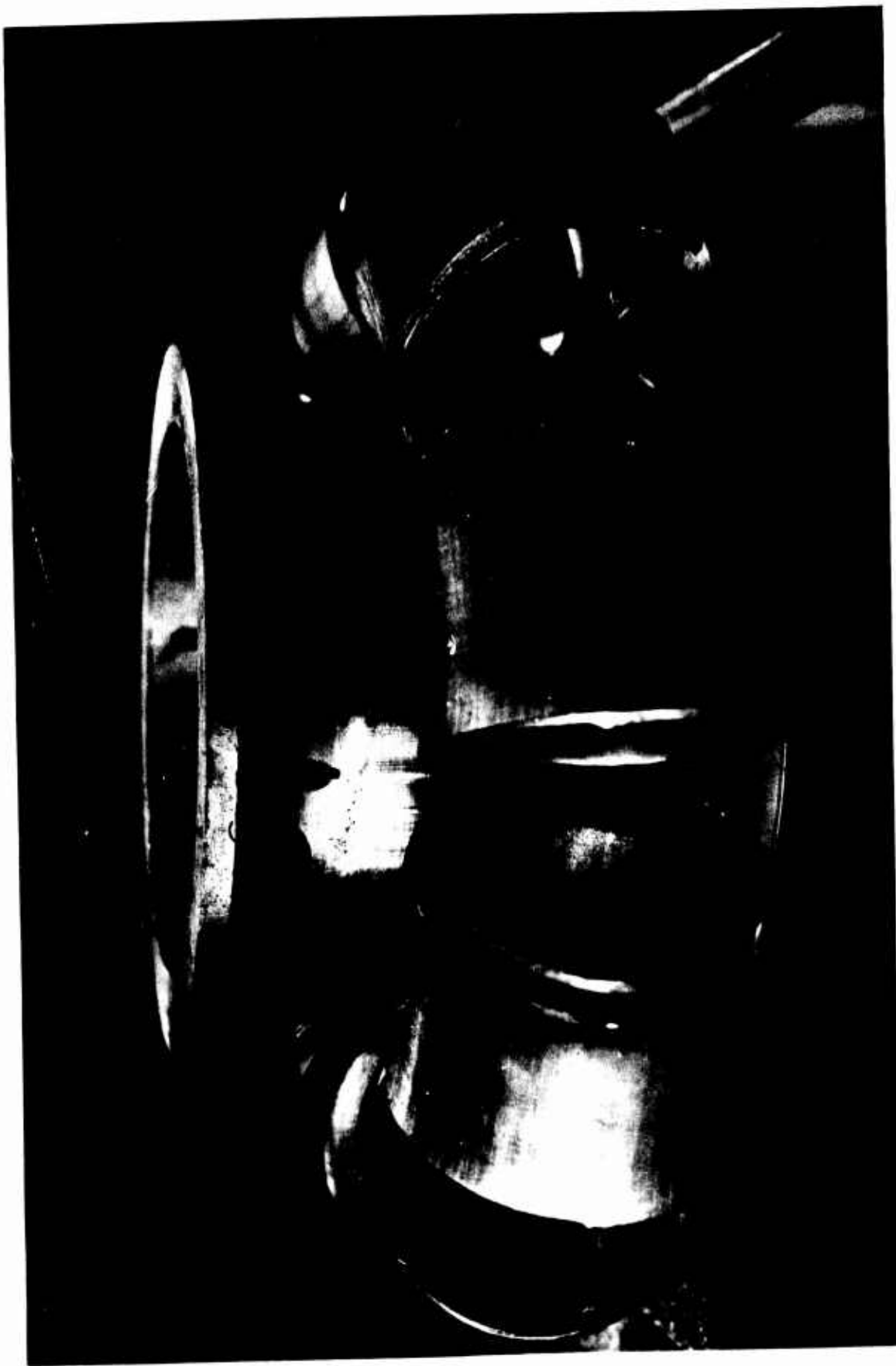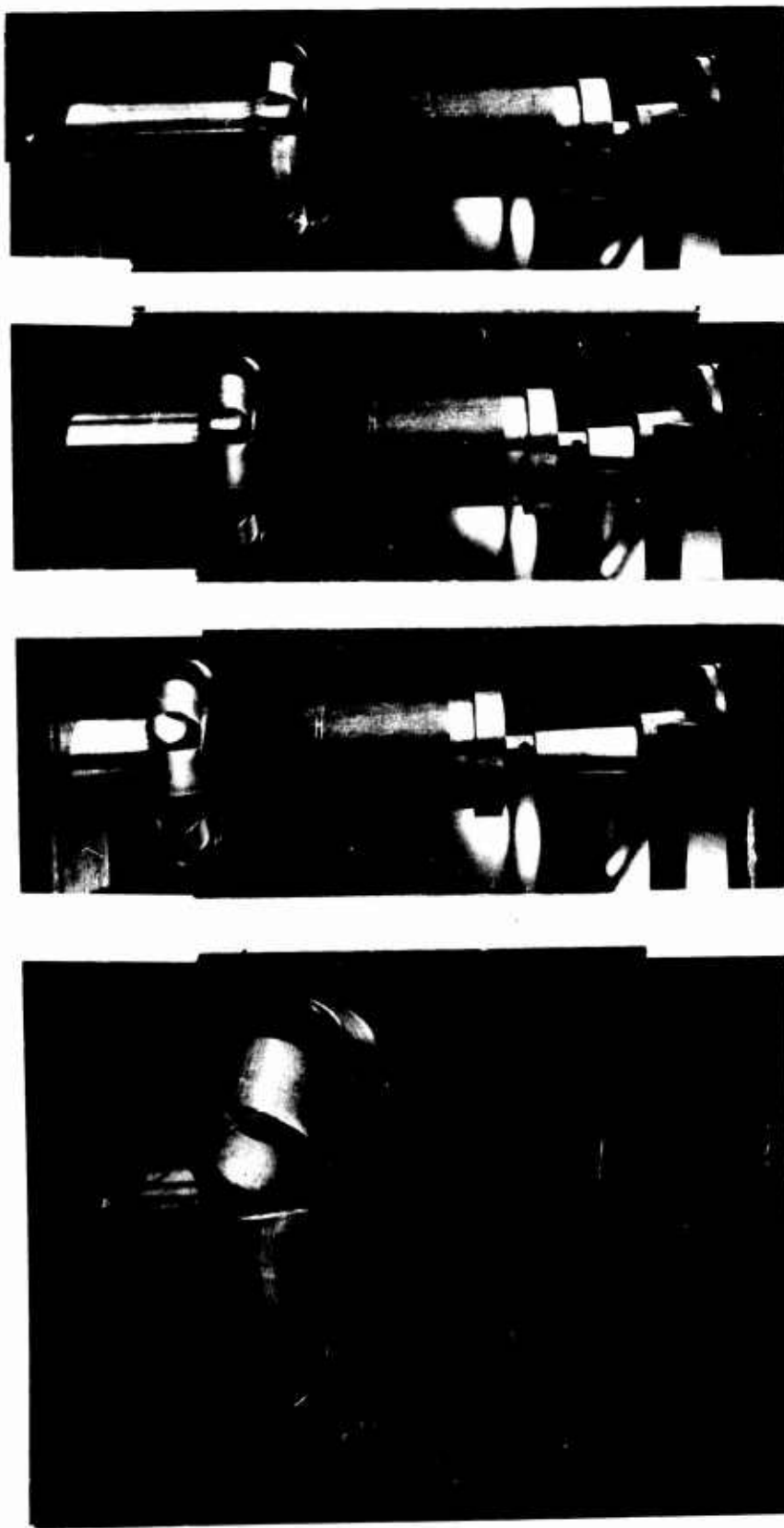
Figure 8 Coiled Tube Buffer and Coiling Collar

Figure 9 Static Tube Coiling Sequence

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SECTION III

FINAL DESIGN AND DEVELOPMENT

3.1 General Description of MAU-91/B Fin Assembly

3.1.1 Original Design (Mod 0)

The Mod 0 configuration and the primary components are shown in Figures 10 and 11. The primary structural member is the support tube. The support tube is rigidly attached at the forward end to the support flange with a threaded connection. At the aft end of the support tube, a clevis is also rigidly attached with a threaded connection. The four fin-drag plates are connected by hinge pins to the clevis. Links, connecting the fin-drag plates with a sliding collar on the support tube, are attached to the fins at a distance of 13 inches from the clevis hinge point. The links are 17 inches in length. The purpose of the collar and links is to assure simultaneous opening of the four fins and to transfer the opening shock forces to the energy absorber.

The tubular aluminum honeycomb energy absorber is located axially on the support tube between the stationary clevis and the sliding collar. The energy absorber serves as a buffer to stop the opening action of the fins at a predetermined angle. The absorber is designed to be crushed 14 inches at an air speed of 600 knots, permitting the fin drag plates to open to an angle of 100 degrees, the maximum angle attainable for the design. At lower air speeds fin opening angles will be correspondingly less than 100 degrees.

The energy absorber is adhesive bonded at the forward end to the sliding collar and slides along with the collar as the fin-drag plates open. The aft end of the absorber contacts the clevis when the fins have opened to an angle of approximately 45 degrees. Crushing of the energy absorber then begins. The geometry of the decelerator is such that as the opening angle increases from 45 to 100 degrees the energy absorber crushes a total of 14 inches.

In the closed position the fin-drag plates lie parallel to the support tube and are retained in that position by the release band. Upon opening of the release band through the action of a release latch, the fin-drag plates are sprung open by the action of leaf springs on the underside of the fins. Further opening of the fins is accomplished by the aerodynamic forces.

The fin assembly is attached to the M117 bomb by means of a set of tooth-like lugs on the support flange which mate with and fit into a similar set of teeth on a bomb adapter flange (see Figure 12). A garter spring, placed in the groove formed by the chamfered forward face of the support flange and the rear face of the bomb adapter flange, applied force to the support flange which retains the mating lugs in intimate contact. Locking pins inserted in two holes in the support flange prevent rotation (and consequent disengagement) of the fin assembly with respect to the bomb.

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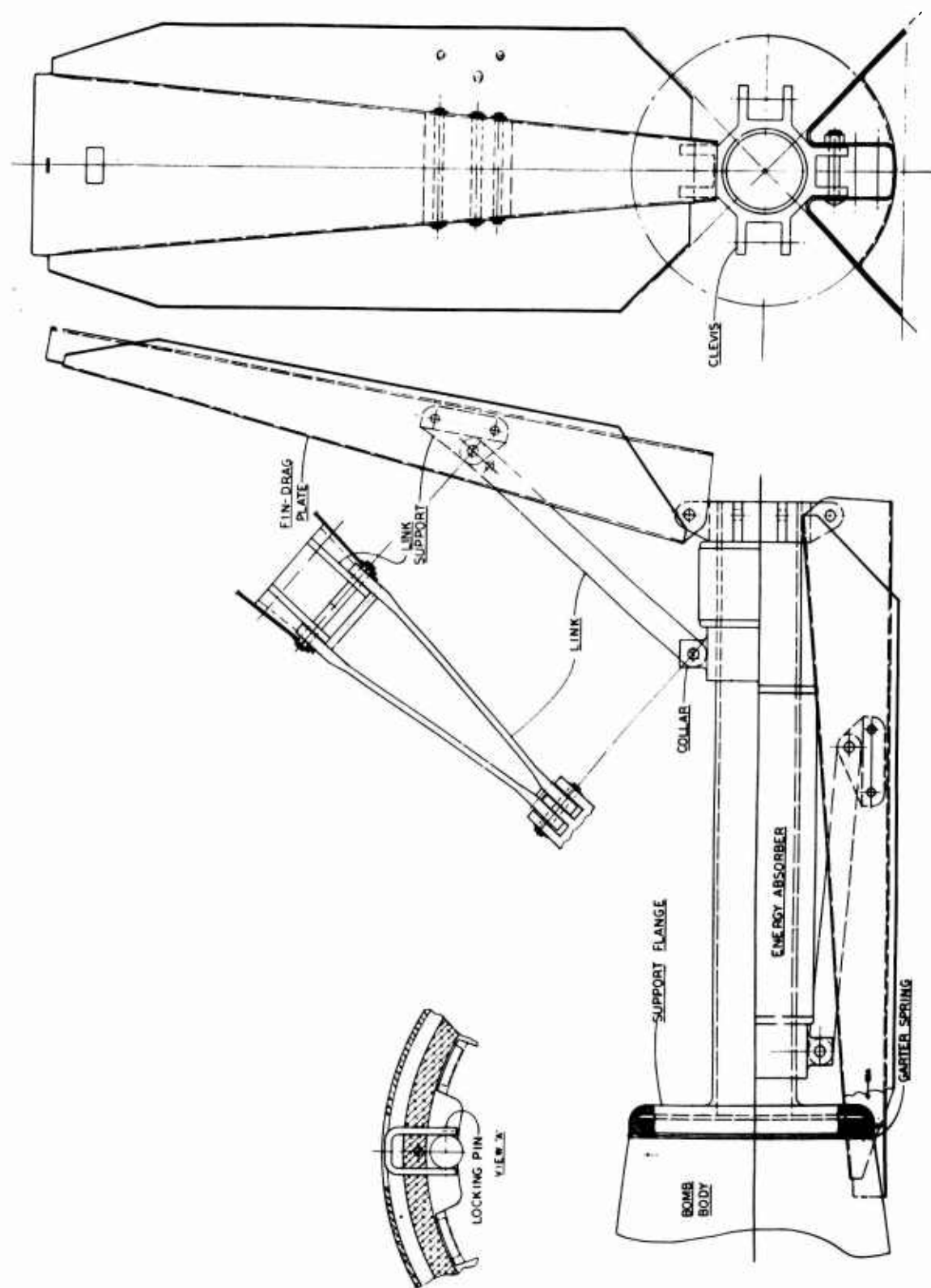
Figure 10 Mod 0 Configuration

Labels in figure: CLEVIS, FIN-DRAG PLATE, LINK SUPPORT, LINK, COLLAR, SUPPORT FLANGE, ENERGY ABSORBER, GARTER SPRING, BOMB BODY, LOCKING PIN, VIEW X

Figure 11 Exploded View of Mod 0

Pip Pins for Lock-
ing Support Flange
to Prevent Rotation

Support Tube

Support Flange

Bomb Body

Bomb Flange Ring
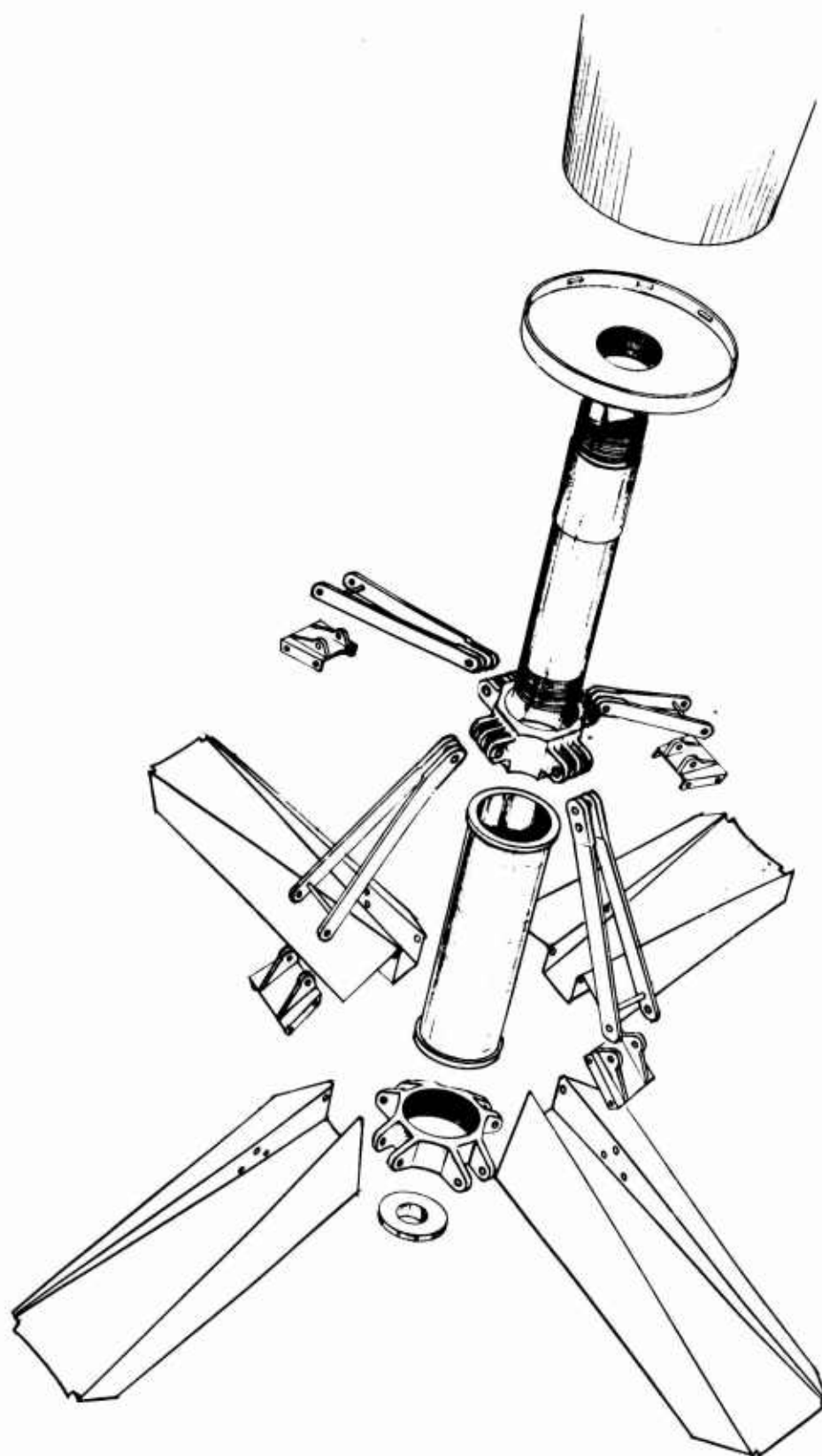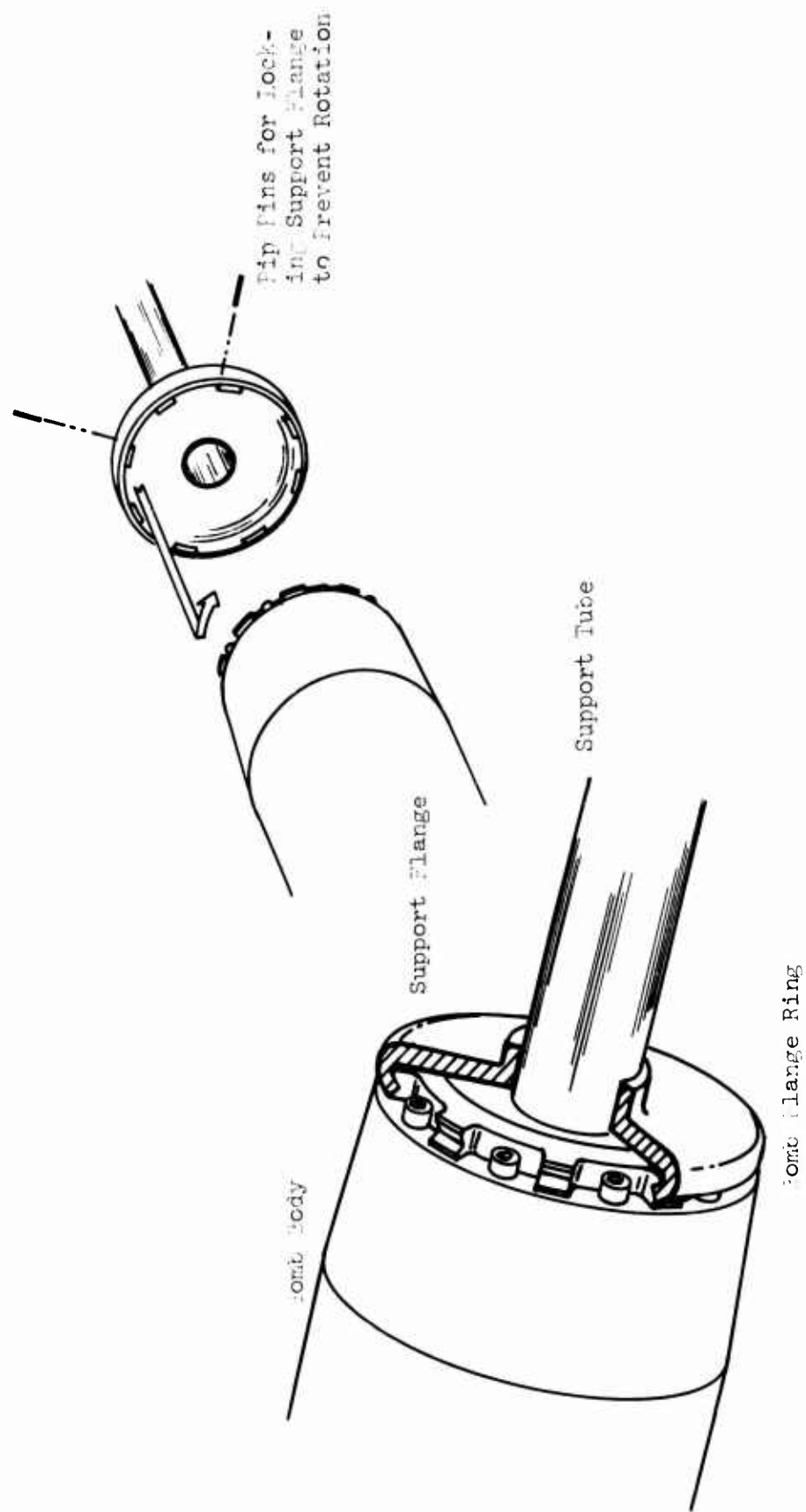
Figure 12 Quick Attach-Detach

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3.1.2 Mod 1 Design

During the flight testing of the Mod 0 design, mixed success was experienced. Those units dropped from the centerline MER at maximum speed functioned satisfactorily; however, those units dropped from various pylon stations at maximum speed often experienced failure of the fin-drag plate. It was concluded from reviewing the films taken of the drops, that the failures were due to the extreme pitchdown encountered when the bomb was released from certain stations. Since the unit would be used on all stations, it was obvious that some design revision would be required. As a result, a significant innovation was incorporated into the design which, by reducing the impact energy, effectively increased the structural strength of the retarder.

The innovation came about as a result of earlier conversations with the project personnel at Eglin, when they described a similar development by the Royal Australian Air Force, which reversed the mechanics of opening. The reversing technique had a great deal of merit in that it reduced the opening velocity of the fins and, thereby, significantly reduced the inertia forces transmitted to the fin-drag plates. This, in turn, significantly reduced the load in the majority of the other components. The difference between the two techniques is illustrated in Figure 13. In the original design (Mod 0), the fin-drag plate pivots at the aft end and the sliding collar moves in the same direction as the relative wind. In this case the airload on the entire surface of the fin-drag plate is converted into kinetic energy which must be taken out by the absorber. The reverse technique (Mod 1), fixes the sliding collar at the flange, and in opening, the aft end of the fin-drag plate moves forward with the clevis in opposition to the relative wind. In this instance the airload on the portion of the fin between the link support and the clevis opposes the opening of the fin-drag plate and significantly reduces the kinetic energy of the system.

In addition to reducing the loading on the decelerator components, it was possible to use all of the parts used in the Mod 0 design in the Mod 1 design, with only minor modifications to the collar, clevis and support tube. The I.D. of the collar was reduced so that the bore of the collar could be threaded, the I.D. of the clevis was increased so that the clevis could slide over the support tube, and the thread on the support tube was increased in length at the flange end and was eliminated from the clevis end. The Mod 1 design is shown in Figure 14, and the commonality of parts is illustrated by comparing the exploded views of the two designs, Figures 11 and 15. The design improvement required only minor changes in the collar and clevis forgings, and the program was not delayed.

The reverse opening technique effectively reduced the opening forces. This is best illustrated by comparing the strength requirements of the energy absorber for each concept. For the Mod 0 concept the energy absorber required a static crush strength of approximately 50,000 pounds, while the Mod 1 absorber required a crush strength of approximately 21,000 pounds. The success of the Mod 1 concept indicated that further changes could be made in the geometry of the unit and further reduction in forces would be obtained; however, because of the extreme urgency of the program, it was mutually agreed between the Air Force and GARD that further changes at this time would not be in the best interest of the Air Force.
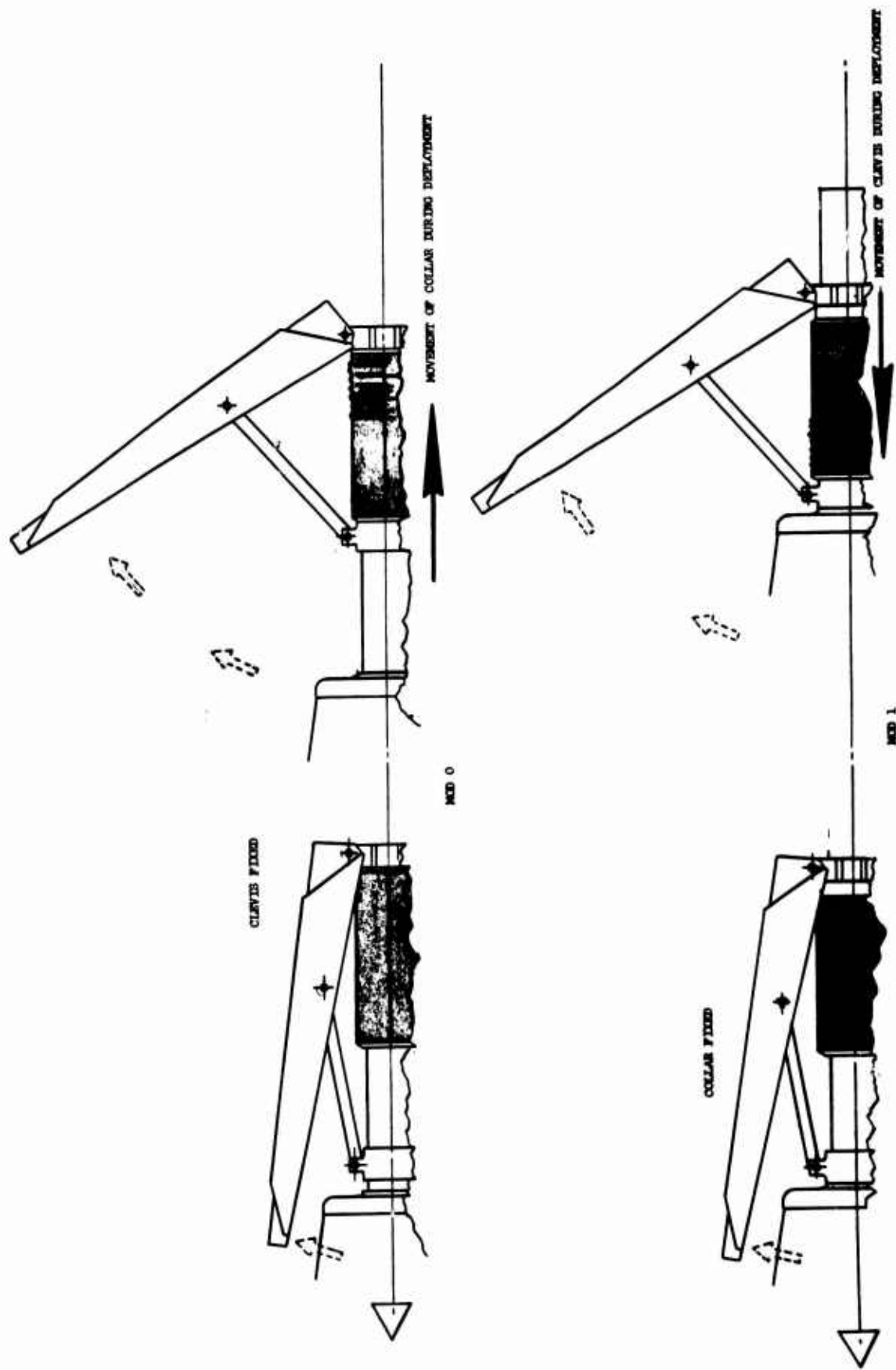
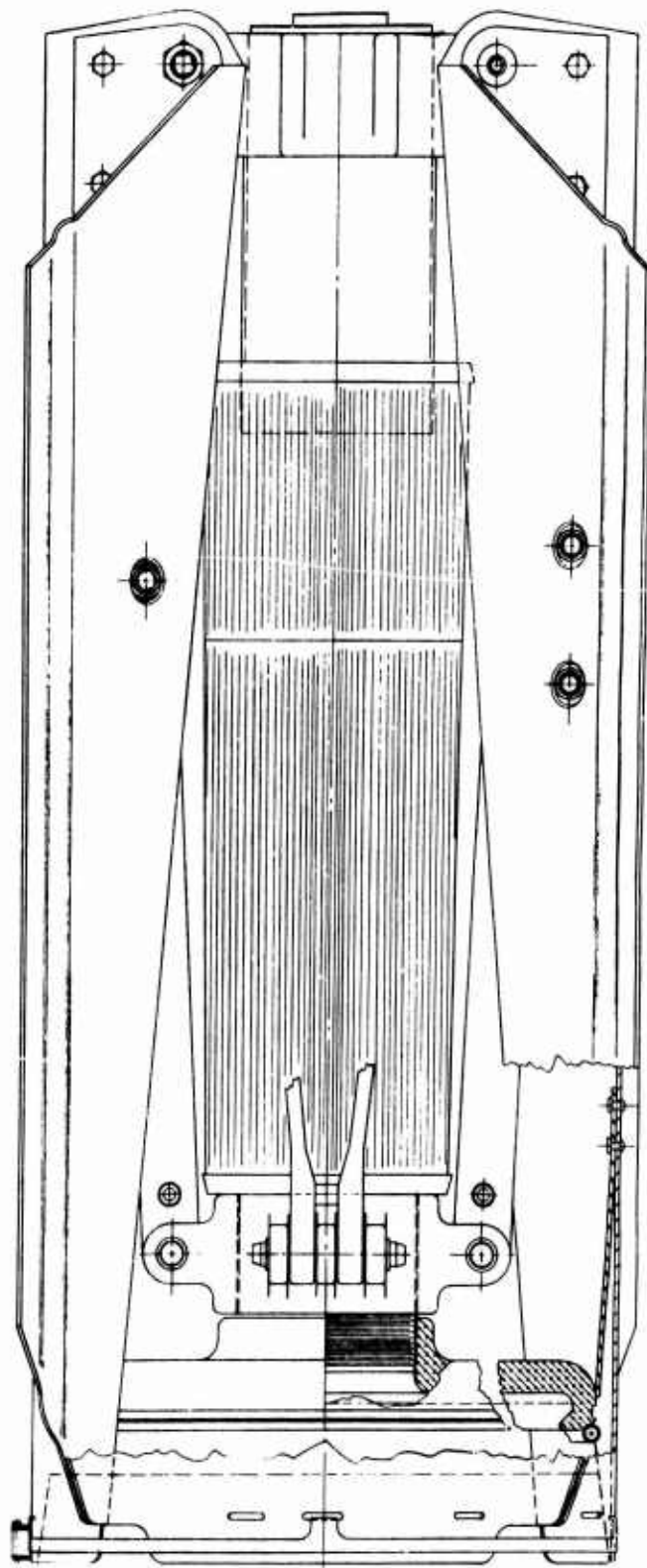Figure 13 Difference in the Mechanics of Opening Between Mod 0 and Mod 1

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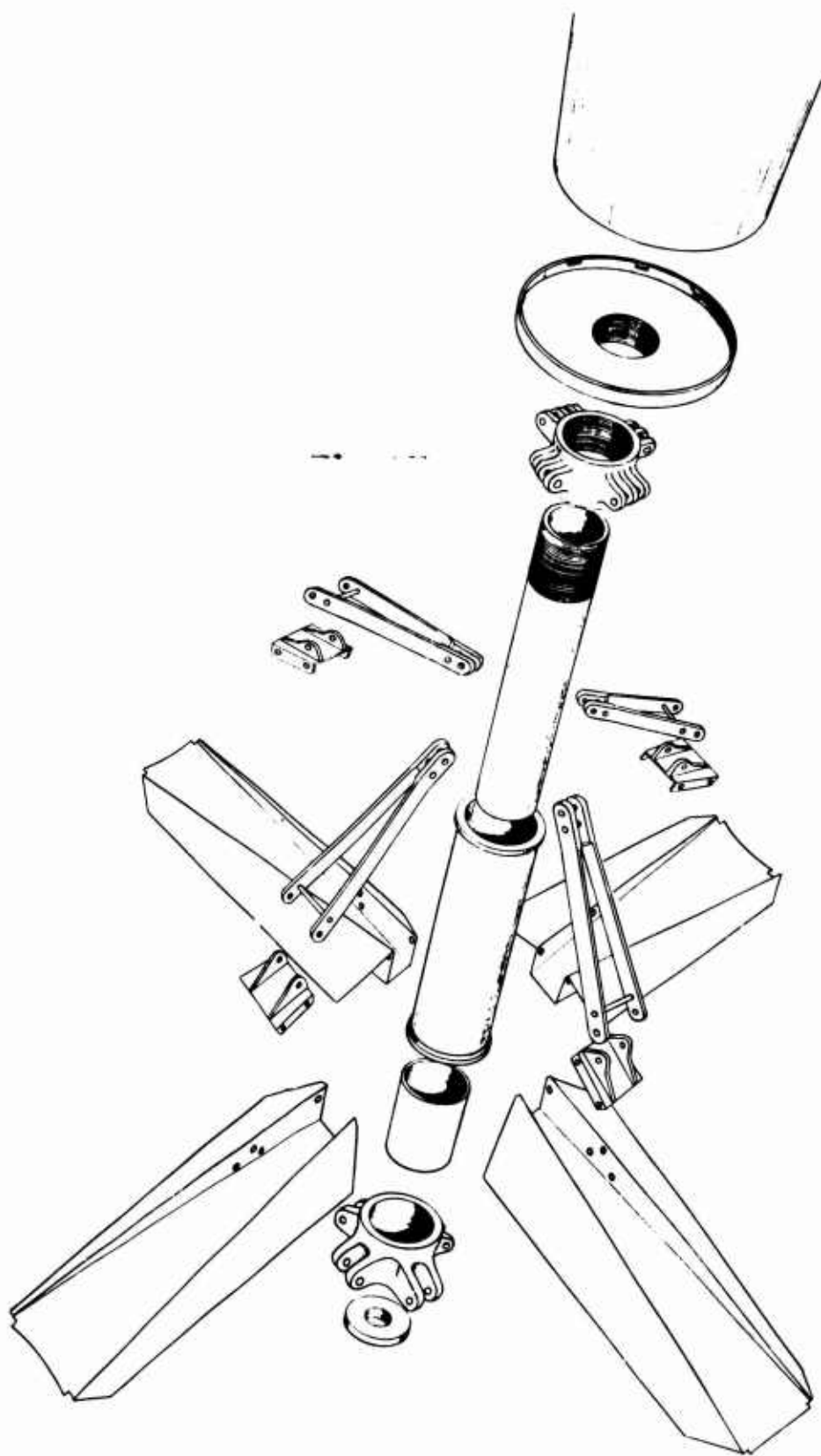Figure 14 Mod 1 Fin Assembly

24

Figure 15 Exploded View of Mod 1

One additional design improvement was incorporated into the Mod 1 design. A doubler plate was added to the fin-drag plate extending from the extreme rear, forward through the link support attachment point. This doubler plate, on both sides of the fin-drag plate (see Figure 16), added strength to the fin-drag plate in two ways: the first, by increasing the bearing area at the attachment points which helped to prevent local failure; and the second was to add strength in bending. It is believed that the greatest gain came from the increase in bearing area at the attachment points which reduced the possibility of a local failure which could propagate to complete failure of the fin-drag plate. The Mod 1 concept was eminently successful from a structural point of view, and went into production essentially unchanged.

During the flight testing of the initial Mod 1 production decelerators at Eglin AFB, a significant number of decelerators dropped in the low drag configuration. In a series of ground tests, in conjunction with the flight tests, it was determined that the arming technique was responsible for failure of the decelerators to deploy. During bomb ejection the arming wire failed, preventing the wire from withdrawing from the band latch mechanism and resulting in failure of the release band to open. This kept the decelerator in the low drag configuration.

The successful solution to the problem involved the use of a double latch mechanism combined with an arming pin and a stainless steel, woven cable used as a lanyard. The double latch mechanism (shown in Figure 17) greatly reduced the force applied to the arming pin by the band latch and the force required to withdraw the pin, while the use of a lanyard to pull a short, heavy pin eliminated the necessity of pulling the long arming wire through the latch mechanism.

As a result of successful flight tests of decelerators using the double latch mechanism and the lanyard, the design was incorporated into the release mechanism of production decelerators.

3.1.3 Model Change Resulting in MAU-91A/B

In order to prevent premature opening of the fins, it was essential that a method be developed for confinement and control of the cable during flight and bomb ejection. As an interim fix, taping down the lanyard, was successfully used (Figure 18). However, it was decided that a channel, in the form of a hat section, attached to the upper surface of the fin housing the lanyard, would be utilized as a permanent fix. The channel houses and confines the lanyard during flight and controls its movement during bomb ejection. Tests of a short length arming cable channel (Figure 19) were successful. Ultimately a longer channel was incorporated into the decelerator production when the length of the lanyard was increased from 72 inches to 100 inches. The decelerator incorporating the channel was redesignated the MAU-91A/B. It is shown in Figure 20.

3.2 Other Developments

3.2.1 Delayed Opening Devices

At the request of the Project Officer, the preliminary design of a pyrotechnic device was undertaken to provide a delay in deployment of the

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6 Bolts for Fastening Doubler
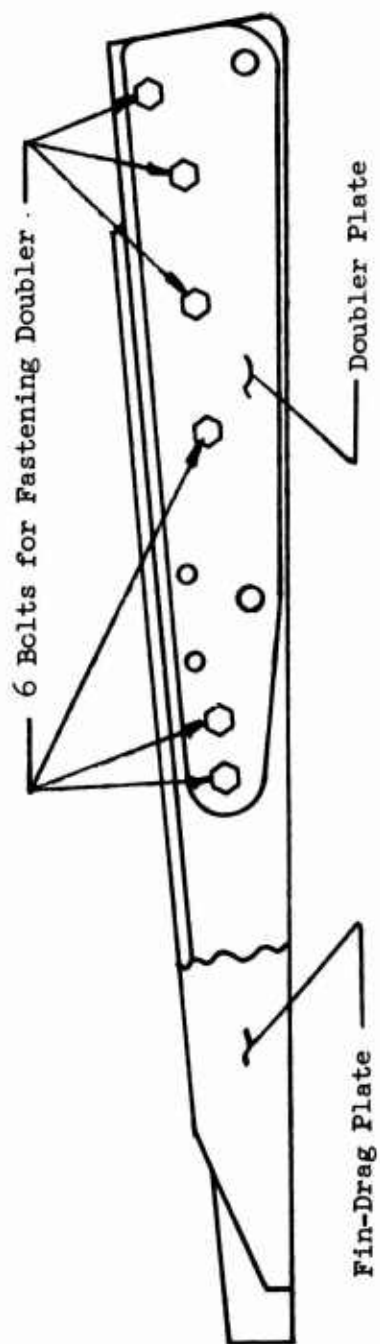
Doubler Plate
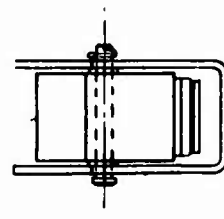
Fin-Drag Plate
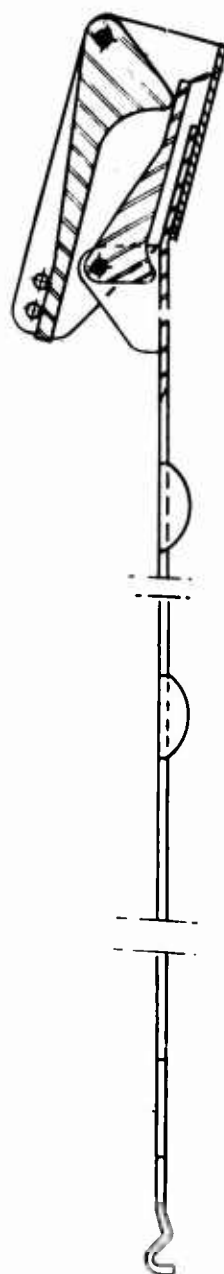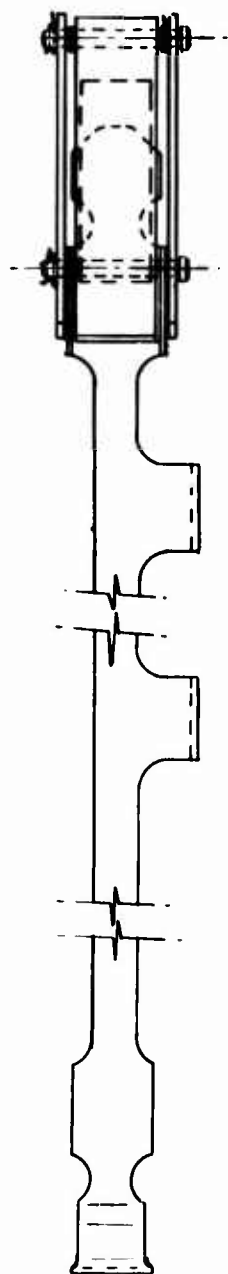
Figure 16 Doubler Added to Fin-Drag Plate

27

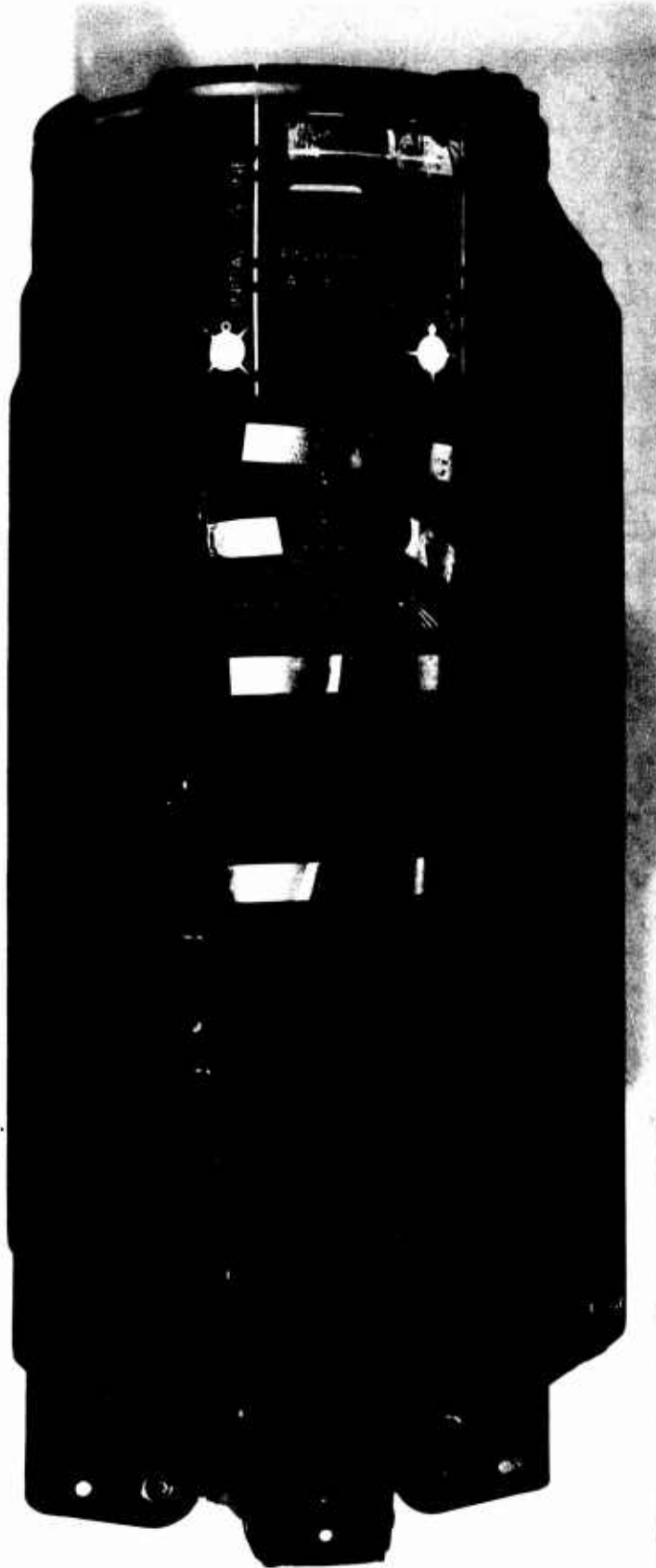Figure 17 Double Latch Release Mechanism
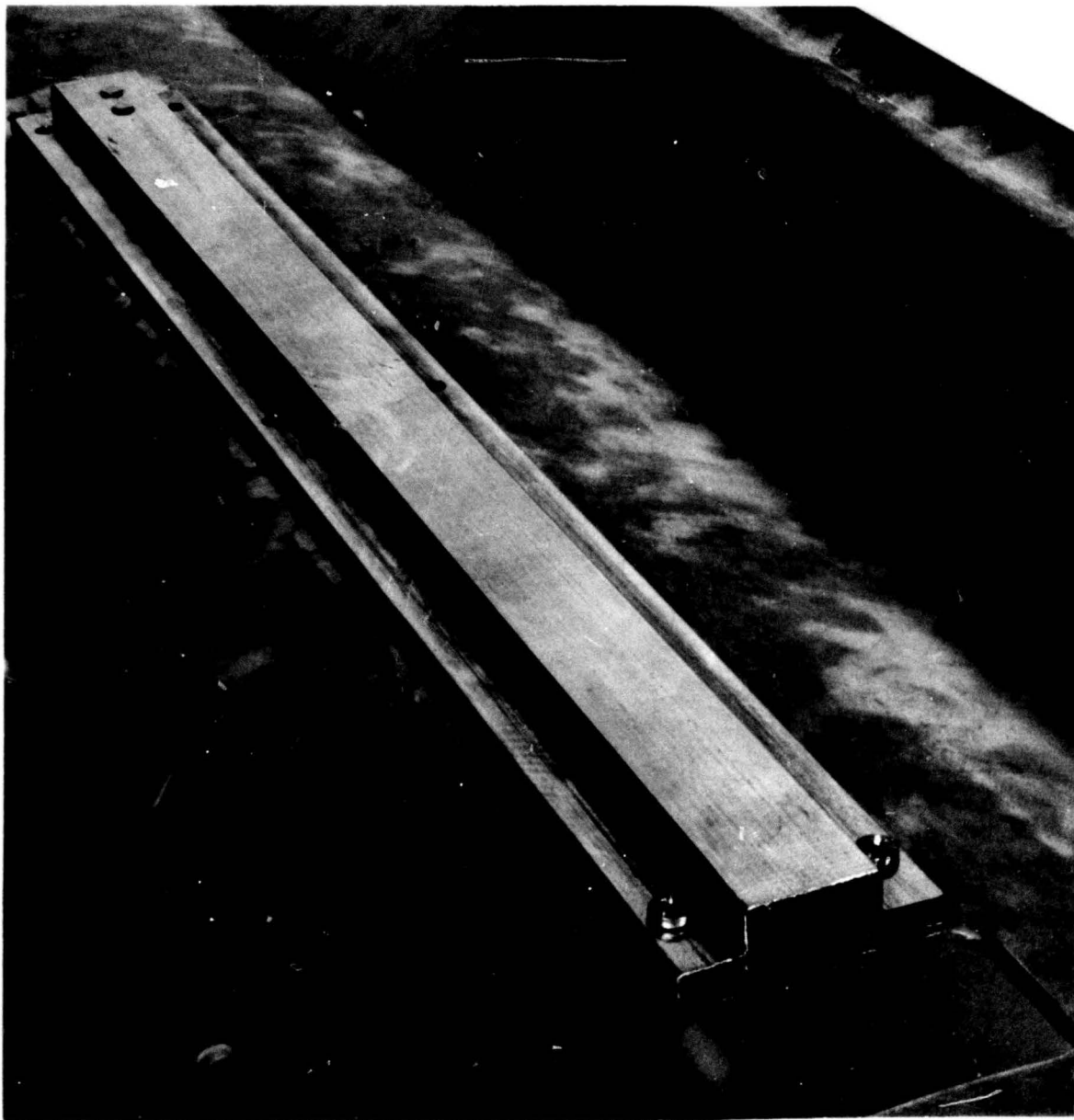
Figure 18 Fin Assembly With Taped Down Lanyard

Figure 19 Lanyard Retainer Channel

30
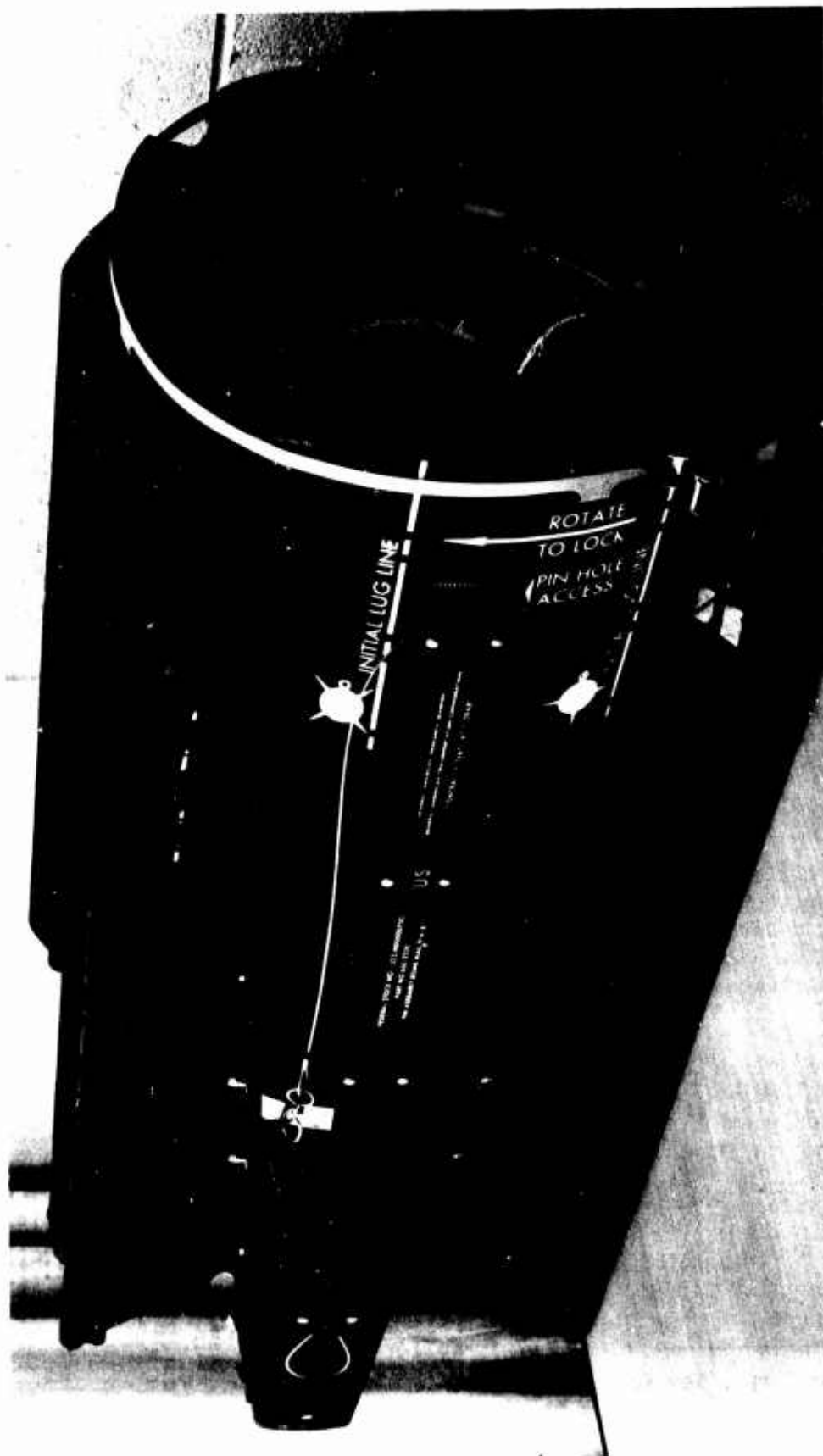
Figure 20 MAU-91A/B Fin Assembly

decelerator fins to be used on bombs dropped internally from a bomb bay. The pyrotechnic device was to be actuated mechanically by essentially the same operation as the band release, directly applicable to 250 and 500 pound SNAKEYE bomb decelerators and adaptable to the 750 pound bomb decelerator. The delay release device was required to provide a delay of approximately 2 seconds with a tolerance of $\pm$ 10 percent. A preliminary design, using standard AN tube fittings as its key components, was prepared; two units of the design were fabricated for demonstration of the concept.

The design performed satisfactorily and a quantity of 216 pyrotechnic delays were fabricated. Nine of the units were test fired with delay times ranging from 2.03 to 2.79 seconds with an average of 2.43 seconds. The remainder were shipped to Eglin AFB. Approximately 100 of the delays were used in airdrops and all but two functioned successfully. For bombing accuracy, a tighter delay-time tolerance was indicated, and would be incorporated in any additional units supplied for testing. A photograph of the delay installed on the MAU-91/B fin assembly is given in Figure 21, and on the Mark 15 in Figure 22.

Work on improving the pyrotechnic time delay design was then undertaken, and successful preliminary tests were conducted. The final configuration is shown in Figure 23. An additional 500 units were fabricated to this design and shipped to Eglin AFB for flight test.

Since it is difficult and very expensive to obtain pyrotechnic delay tolerances of the magnitude required, a mechanical approach was investigated. The system was, again, intended for use in internal carriage in the B-52 aircraft. Two approaches were considered: (1) a mechanical timer system, and (2) a system using a lanyard. It was decided that the latter was the more positive and simpler approach, especially with the use of a long lanyard. The delay device developed consisted of a 17 foot long lanyard made of stainless steel braided cable, stored in fabric pockets wrapped around the bomb like a belt and fastened with Velcro*. The design is shown in Figures 24 through 27.

A series of drop tests were performed from the Static Drop Tower at Eglin to test the operation of the delayed opening device. All static tests were successful. The device was then flight tested from a B-47 aircraft at Eglin; the results were very successful, and a total of 1,000 delay devices were fabricated and delivered to Eglin for evaluation testing from the B-52 aircraft.

Two series of B-52 tests were performed at Eglin with the delay device, and both series used the MAU-91A/B and the Mark 15 fin assemblies. In the first series of tests, the lanyard was fabricated from 1/16 inch diameter cable, which, at the time of shipment, was standard on the MAU-91A/B fin assembly. The test consisted of a 12 hour flight with the bomb bay open for ten minutes at 350 knots, a return to base, and a check of the units. On the initial test, it was found that one of the storage straps had opened and allowed a fin assembly to deploy, and at another station the arming pin had been partially pulled. These tests were performed on the Mark 82 bomb equipped with Mark 15 fin assembly.

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* Velcro Corp., New York, New York.
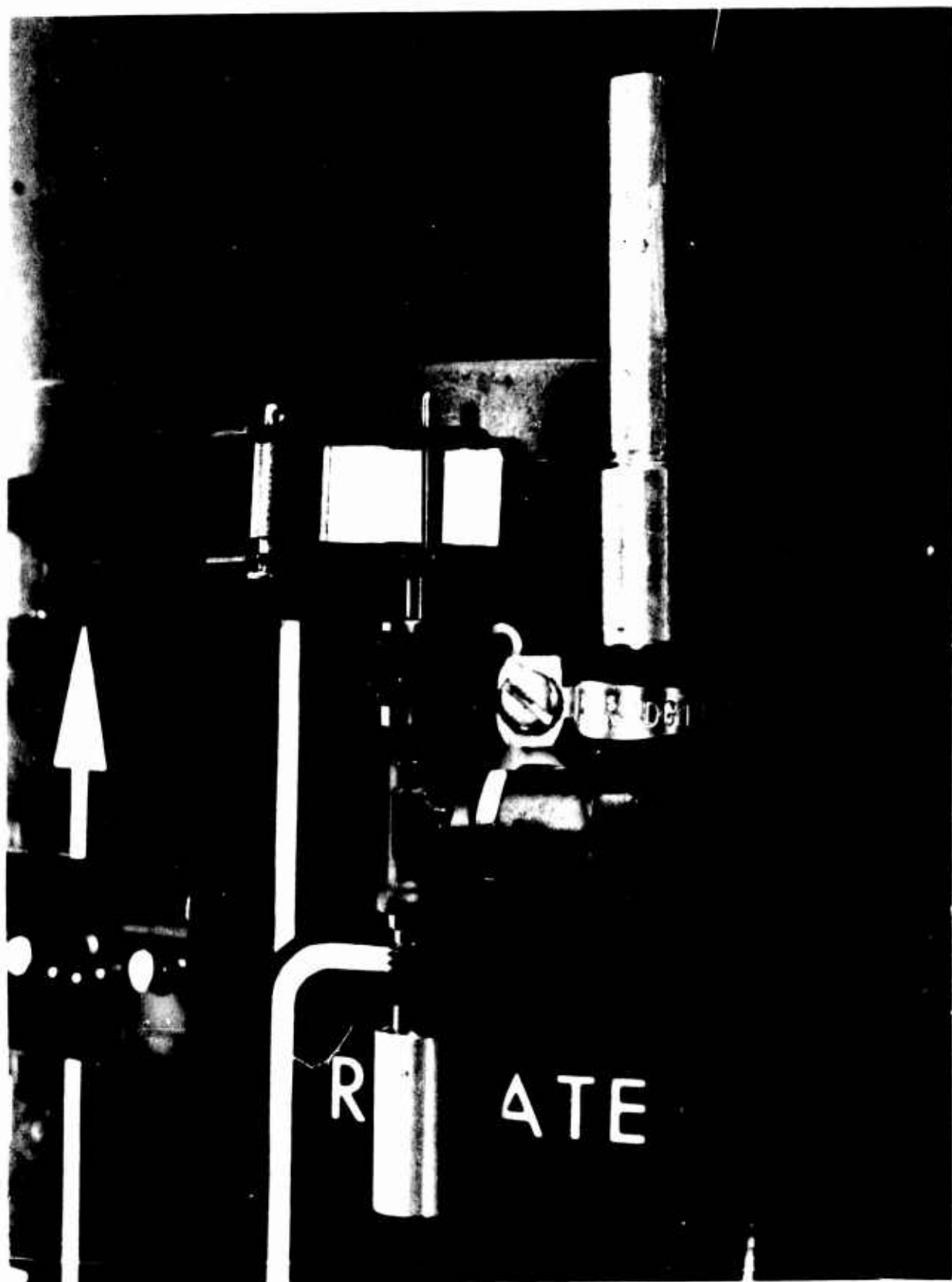
Figure 21   Preliminary Pyrotechnic Delay Device on MAU-91/B Fin
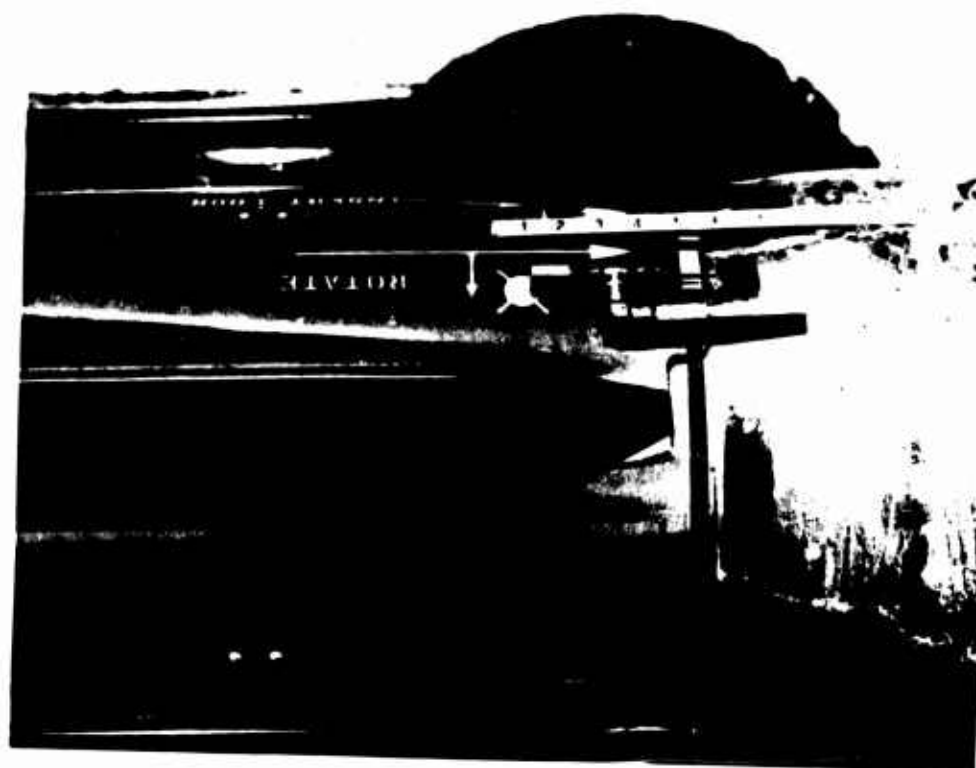
Figure 22   Preliminary Pyrotechnic Delay Device on Mark 15 Fin
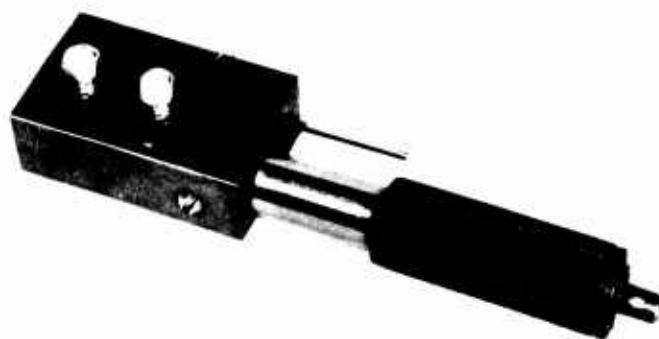
Figure 23 Pyrotechnic Time Delay

"VELCRO" FOR FASTENING
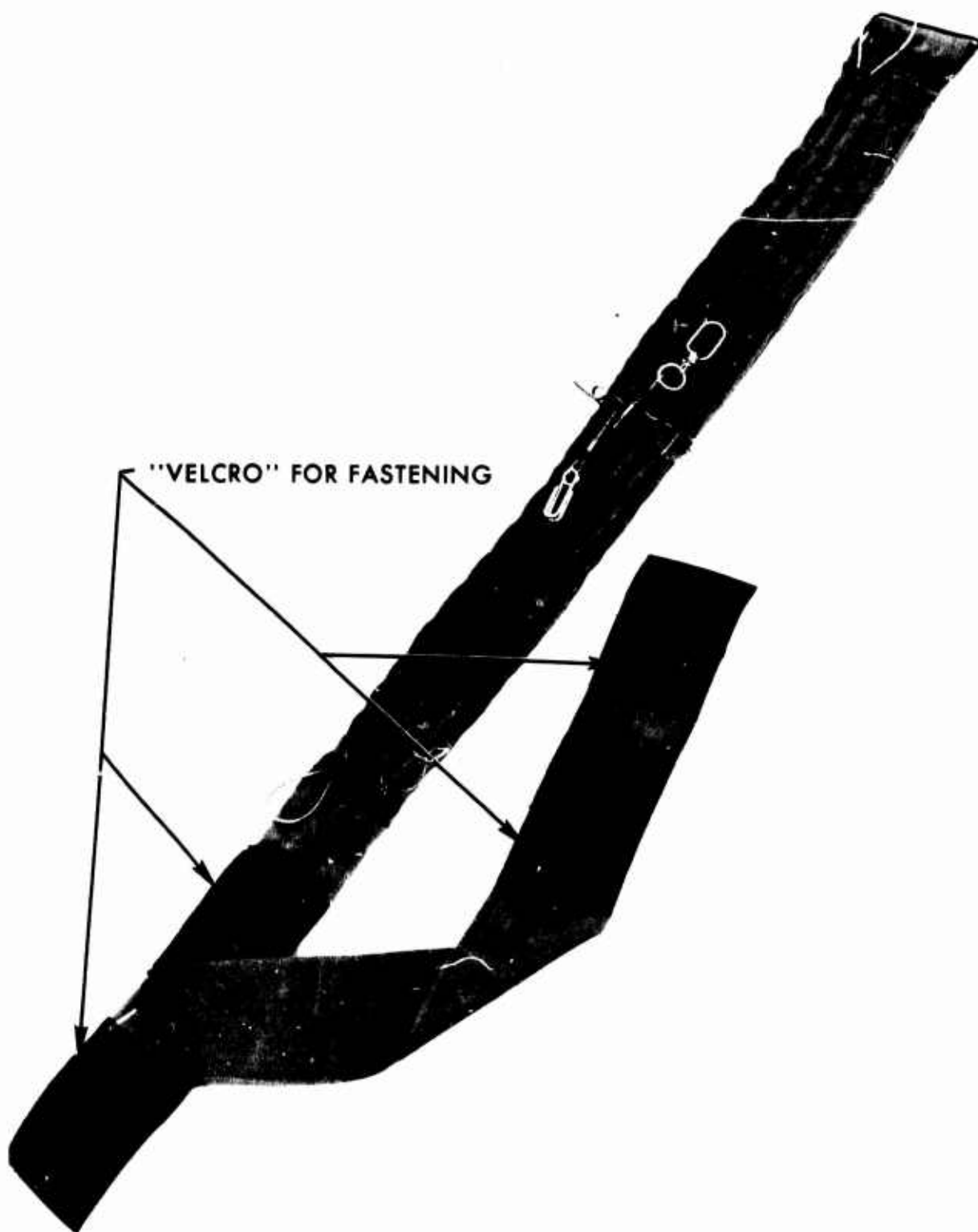
Figure 24   Assembled Delay Device for 750 Pound Bomb

REMOVED IN FIELD WHEN
DEVICE IS USED ON 500
POUND BOMB

Figure 25   Assembled Delay Device Modified for 500 Pound Bomb

BUCKLE USED TO MAINTAIN TENSION ON STRAP
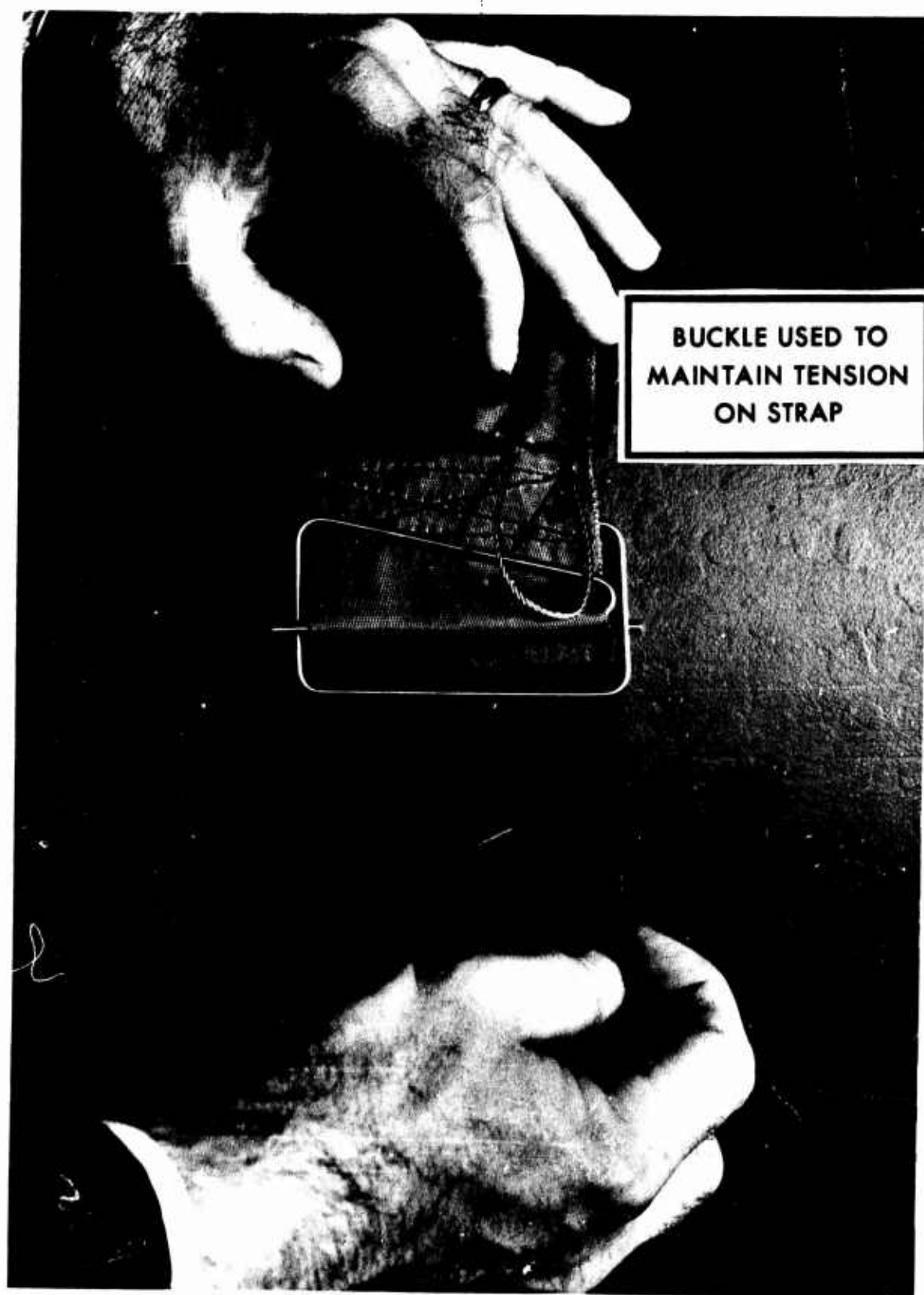
Figure 26   Inserting End of Delay Device Strap through Tension
Buckle (750 Pound Bomb)
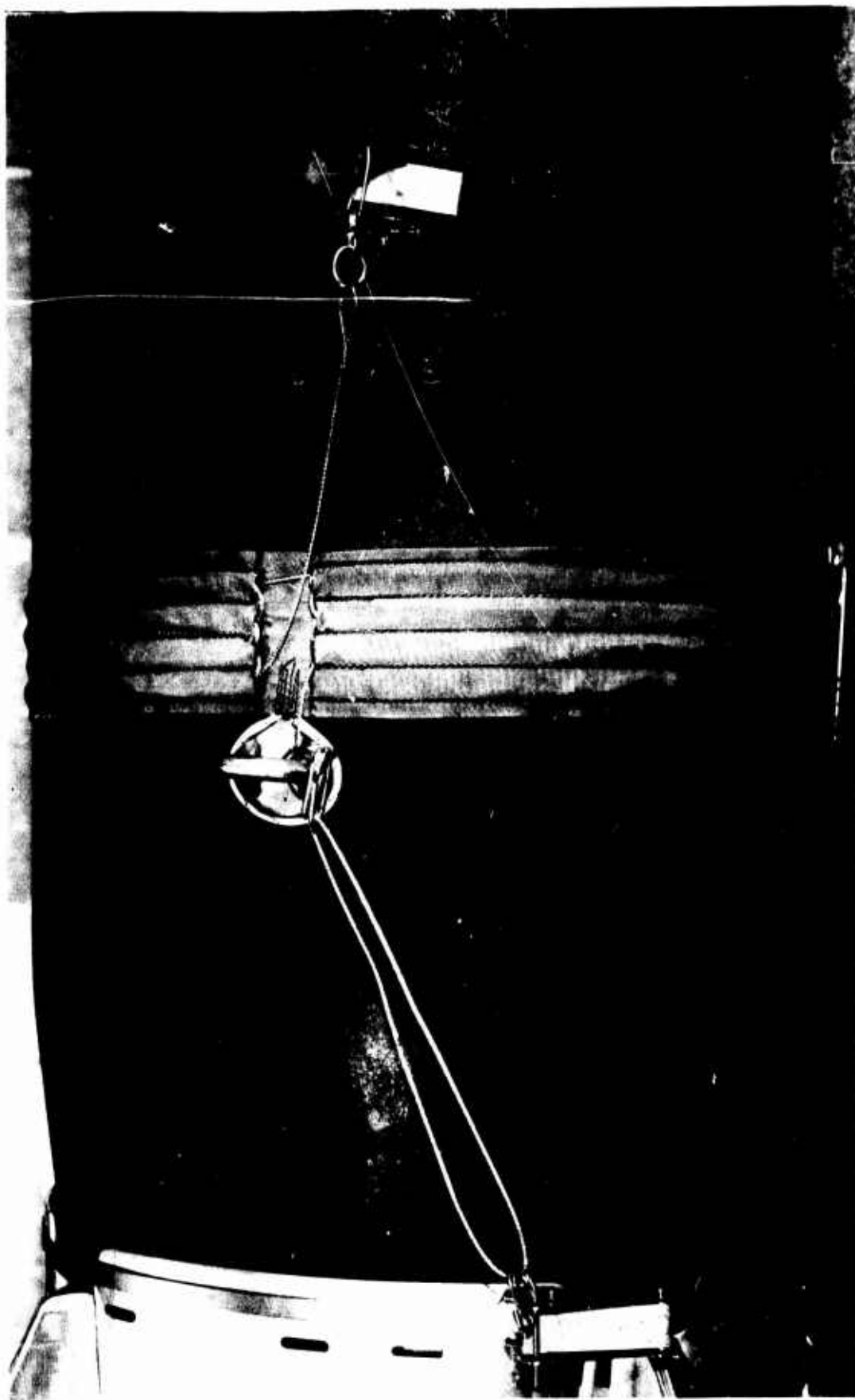
Figure 27 Delay Device Installed on 750 Pound Bomb

An immediate fix was made upon approximately 60 storage straps. This fix (Figure 28) incorporated an additional flap of Velcro which when fastened presented a sealed face to the air flow. Also, Fahnestock clips were put on the arming pins to secure them before deployment. Two more B-52 flights were made with internal loads of the Mark 82 bomb/Mark 15 fin, and the M117 bomb/MAU-91A/B fin. Again, these flights were for 12 hours with the bomb bay doors open for 10 minutes at 350 knots. A check of the units after the flights revealed that the storage straps performed satisfactorily and were not affected by the air stream while the bomb bay doors were open.

After the modification proved satisfactory, a number of drop tests were made with the Mark 15 fin utilizing a delayed opening lanyard fabricated from 1/16" diameter cable. These tests were only partially satisfactory since several cables failed, after pulling the arming pin and allowing the fins to deploy, before breaking the swivel. This allowed a length of lanyard to remain in the bomb bay. It was then decided to replace the 1/16 in. cable with 3/32 in. diameter cable. Since the storage straps had already been fabricated for the 1/16 in. cable, a 3/32 in. diameter cable consisting of 7 x 19 strands was used in place of the standard 3/32 in. diameter, 7 x 7 strand, cable because of the greater flexibility of the 7 x 19.

Several flights were made dropping the M117 and the Mark 82 bombs equipped with the delay device, using the 3/32 in. diameter cable. These tests were successful. The only problem occurred with the Mark 82 bomb when dropped from the rear, upper left, station, in the aft bomb bay. The Mark 15 fin deployed prematurely on three separate occasions and scratched the bomb bay door. Assessment of the motion pictures taken during these tests indicated that the arming pin was pulled prematurely, when snagged by a cable from a bomb released earlier, before the cable had been fully deployed from the storage strap. This was prevented in later drops by repositioning some of the stowage straps. Additional flight tests utilizing the device were successful, and Class I Drawings were prepared and sent to the Air Force.

3.2.2 Arming Cable Guide

On a significant number of F-100 drops the bombs went low drag because of broken lanyards. This was caused when the rear thruster slipped off the rear bomb lug during deployment and cut the lanyard just behind the lug. An immediate fix involved routing the lanyard through the NATO lug placed in the lifting receptable on top of the bomb. The new production M117 bombs do not have provisions for the NATO lug; therefore, another means for routing the lanyard around the rear suspension lug was required.

An arming cable guide to reroute the lanyard around the rear bomb lug (Figure 29) was devised and tested. The tests were successful, but there was some interference between the guide and the pylon at certain weapon stations. The guide was modified (Figure 30) to alleviate the interference and ten guides were fabricated and shipped to Nellis AFB for testing. A number of the revised guides were tested and the test results were satisfactory. However, the units tested contained the 1/16 inch diameter arming cable lanyard and a number of these failed after pulling the arming pin but before breaking the swivel. This left a part of cable attached to the aircraft and caused minor aircraft damage. This problem was alleviated by using the 3/32 inch diameter cable which had been adapted as standard on the production MAU-91A/B.

An additional 180 arming cable, guide plates were fabricated and shipped to 7th Air Force Headquarters in SEA. The guide plates performed satisfactorily, and Class I Drawings were prepared and submitted to the Air Force.

Added Velcro

Added Flap

AIRFLOW
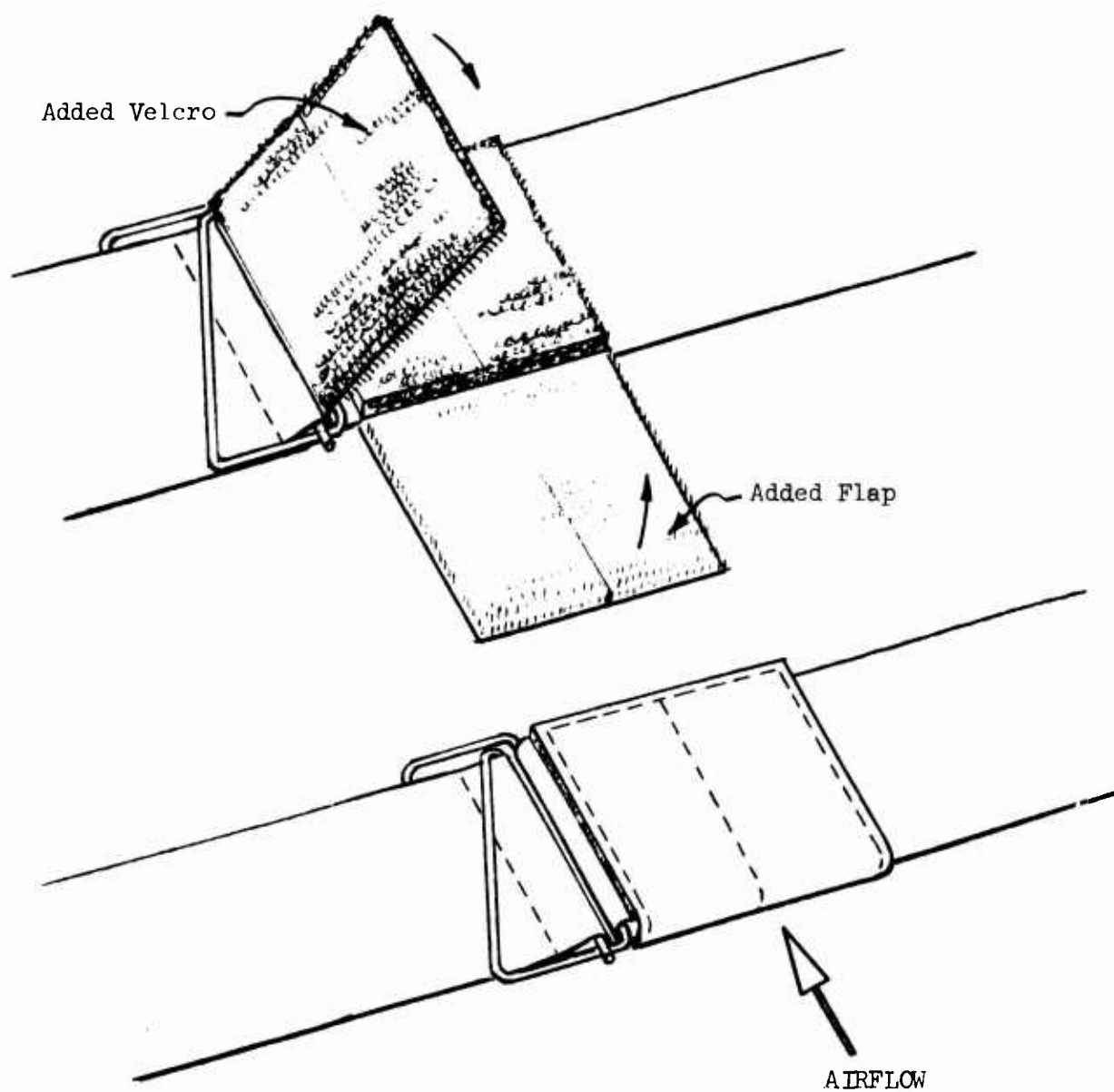
Figure 28 Modified Stowage Strap
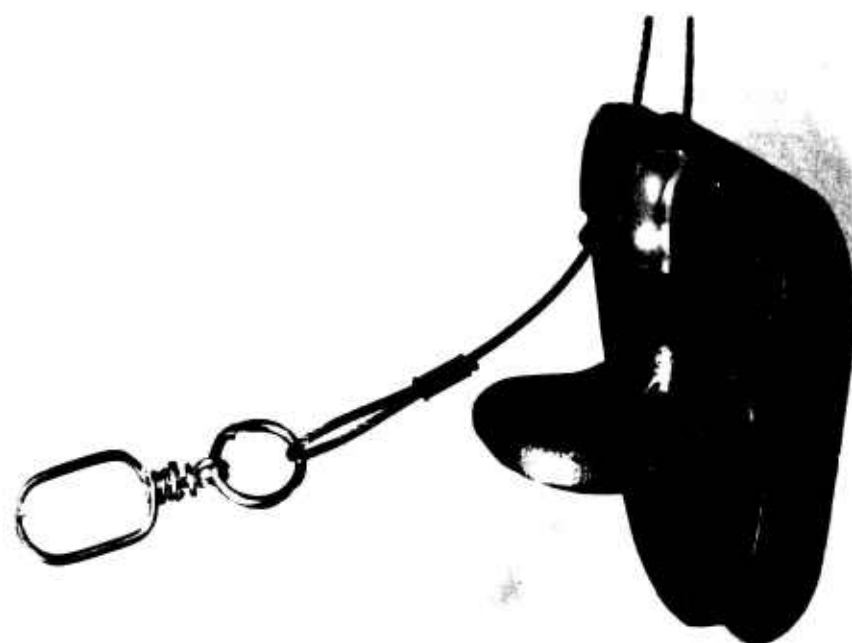
Guide in Position on Bomb Lug
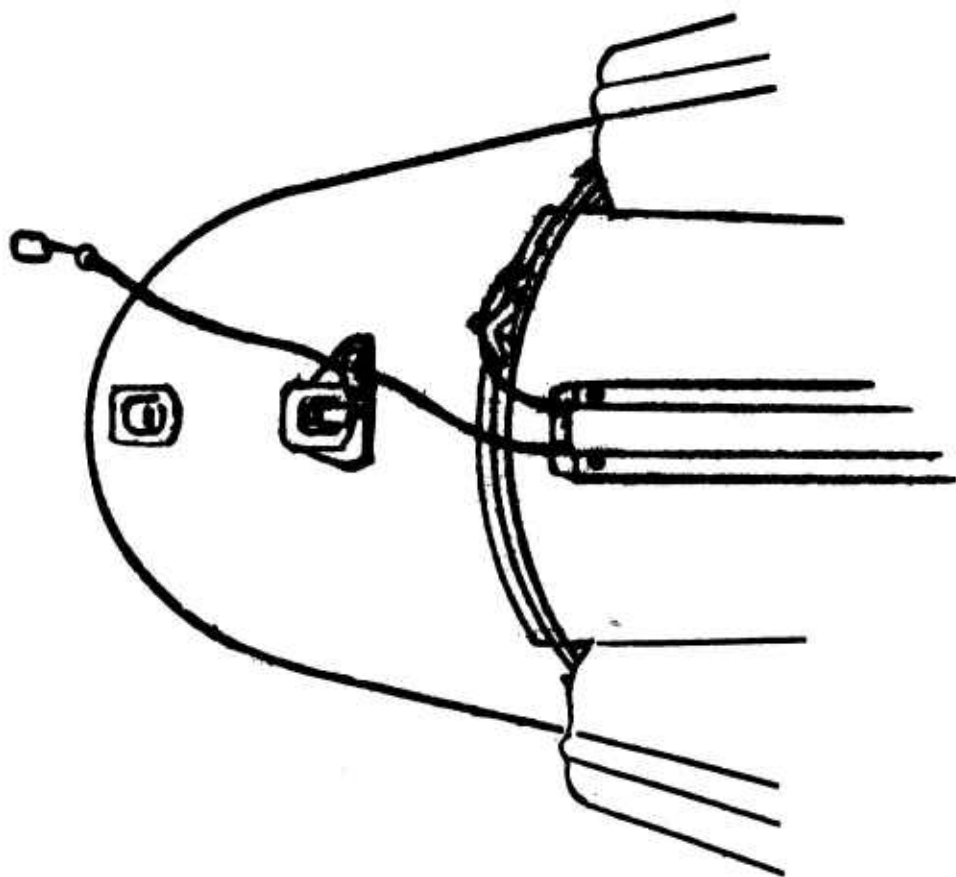
Guide and Arming Cable in Position
for Loading Bomb on Aircraft

Figure 29   Arming Cable Guide

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Figure 30 Modified Arming Cable Guide Plate

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SECTION IV

STRUCTURAL INTEGRITY OF FIN ASSEMBLY

4.1 Structural Analysis

A complete structural analysis was made of the MAU-91/B Fin Assembly. In the analysis, all external loads were calculated for maximum air speed of 600 knots where maximum aerodynamic loading occurs. At a speed of 600 knots, a maximum total loading condition occurs on the decelerator components and at any speed lower than 600 knots, a lesser loading occurs.

An estimate of the buffer force exerted by the energy absorber was obtained from energy considerations by assuming a conservative (frictionless) system and by equating 90 percent of the total work done by the aerodynamic forces on the fin-drag plates to the energy absorbed by the crushing honeycomb tube. The 10 percent reduction in the energy input was assumed to account for the effects of relative velocity between the fin-drag plates, while swinging open, and the bomb. A constant magnitude buffer force will give a minimum load on the decelerator components, and was approximated with the actual absorber.

Bending moments on the support tube, caused by pitching motion of the bomb, were calculated with the fin-drag plates in the fully extended position. The moments were later combined with the tensile force in the support tube, i.e., the reaction of the aerodynamic drag on all four fin-drag plates, to determine the decelerator-to-bomb attachment loads.

Each of the individual components of the decelerator was subjected to a stress analysis. The limit stresses were determined and multiplied by an ultimate load factor of 1.5. The ultimate strengths of component materials were used as the basis for computing margins of safety and the least margin of safety was calculated for each component. The complete structural analysis for the M117 decelerator (Mod 0) was reported in Reference 1. A summary of the minimum margins of safety determined from that structural analysis is given in Table II.

A supplementary structural analysis was prepared for the Mod 1 configuration, the reverse opening design. The primary purpose of the supplementary study was to analyze those critical components where significant changes in loading occurred as a result of the revised decelerator design. In the modification, the various decelerator components, except for the collar, clevis and energy absorber, remained unchanged. The clevis and collar changes were minor--the original lug dimensions were retained and weight did not change appreciably. The shape of the Mod 1 energy absorber is similar to that of the Mod 0 absorber but the static crushing strength of the Mod 1 absorber was reduced from approximately 50,000 pounds to 21,000 pounds. The supplementary analysis was made only for the changed components.

A secondary purpose of the study was to analyze and comparatively evaluate the need for doubler plates on the Mod 1 version standard fin, and to investigate the need for doubler plates on a fin fabricated from thicker material.

TABLE II.   MINIMUM MARGINS OF SAFETY

MOD O DESIGN

Drawing No.	Title	Type of Stress	Margin of Safety
1267-C-1301	Collar	Lug Tearout	0.26
1267-A-1011	Pin	Bending	1.04
1267-C-1203	Clevis	Lug Tearout	1.01
AN-30-60	Clevis Bolt	Bending	0.70
1267-C-1007	Link	Lug Tearout	1.49
1267-A-1008	Spacer	Column Buckling	5.96
1267-D-1101	Fin-Drag Plate	Bearing	0.32
1267-A-1106-3	Pin	Bending	0.21
1267-B-1202	Support Tube	Bending & Tension	0.52
1267-D-1201	Support Flange	Bending	0.04
1267-A-1105	Fin Spring	Bending	0.09
1267-C-1003	Garter Spring	Torsion	0.55

The supplementary structural analysis was reported in Reference 2. A summary of the margins of safety at limit load for the more critical components of the Mod 1 configuration of the fin assembly is given in Table III. On the basis of the structural analysis, it was concluded that the collar and clevis have adequate strength to withstand the applied loads. It was further concluded that the standard fin-drag plate still needed doubler plates in the Mod 1 design; even a thicker fin material (.160 inch) would still require doubler plates and no cost savings would be realized.

4.2 Static Tests

The structural integrity of the Mod 0 fin assembly was assessed by a series of static tests. The tests were designed to simulate the combined dynamic and air loads experienced by the fin assembly in actual service operation. Individual component strength was determined on a "weakest link" basis from results of tests conducted on the composite fin assembly.

The two-fold purpose of the tests was: (1) to evaluate the accuracy of the structural analysis in predicting the component stresses by comparison with the experimentally determined stresses; and (2) to evaluate the strength of the fin assembly by loading it to levels in excess of the estimated limit loads.

Evaluation of structural analysis accuracy was accomplished by applying test loads at the estimated limit load levels. The strength evaluation involved application and gradual increase of loads until some component (or components) began to yield or actually failed. The latter procedure established only the load at which the weakest member (or members) of the assembly failed. The failure loads for other individual components were assumed to be in excess of the load at which the weakest member failed, however, such loads were not determined in the tests.

The stresses in critical components were measured with the aid of strain gages affixed at the most critical locations. Strain measurements were obtained with a Direct Strain Recorder. All tests were conducted using a slow (static) rate of load application.

4.2.1 Fin Tests

The first series of tests were performed to evaluate the elastic stability and strength of the fin-drag plate together with the link support, link support pin, link bolt and link assembly. An overall view of the test setup, showing the fin-drag plate and link assembly installed in the loading facility, is given in Figure 31. The test fixture was designed to align the applied load with the estimated direction of the resultant of the air and inertial loads.

A series of six fin tests were conducted--Tests 1, 2 and 3 at link orientations of 61, 74 and 87 degrees with limit load applied; test 4 at 87 degrees with ultimate load applied; test 5 at 87 degrees with 250 percent of limit load; and test 6 at 87 degrees, with link support removed, with increasing load applied until failure occurred at 186 percent of limit load. Test 5 was intended to result in failure of one of the components. When it did not, the link support was removed and in test 6 the load was transferred to the

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TABLE III.   SUMMARY OF MARGINS OF SAFETY AT LIMIT LOAD

MOD 1 DESIGN

Component and Mode of Failure	Variation #1 (.125 in. thick fin-drag plate)	Variation #2 (.125 in. fin with .125 in. doubler plates)	Variation #3 (.160 in. thick fin-drag plate)
FIN-DRAG PLATE			
1. Bending:			
a) Compression yield at edge of fin	1.15	1.17	1.75
b) Tension yield at extreme fiber	.97	⌐.19	1.44
c) Buckling of curved panel	.113	.112	1.34
d) Tension yield at link hinge hole	.043	.235	.35
2. Bearing Yield:			
a) At link hinge hole	-.265*	.47*	-0.06*
b) At clevis hinge hole	-.01	.98	.27
LINK	All Variations		
Lug tearout	1.40		
CLEVIS			
1. Compression yield due to ring bending	2.83		
2. Lug tearout	1.06		
COLLAR			
1. Tension yield due to ring bending	.30		
2. Lug tearout	.33		

* These values are based on the assumption that the link support is not used, the entire link load being transferred through a single hinge pin.
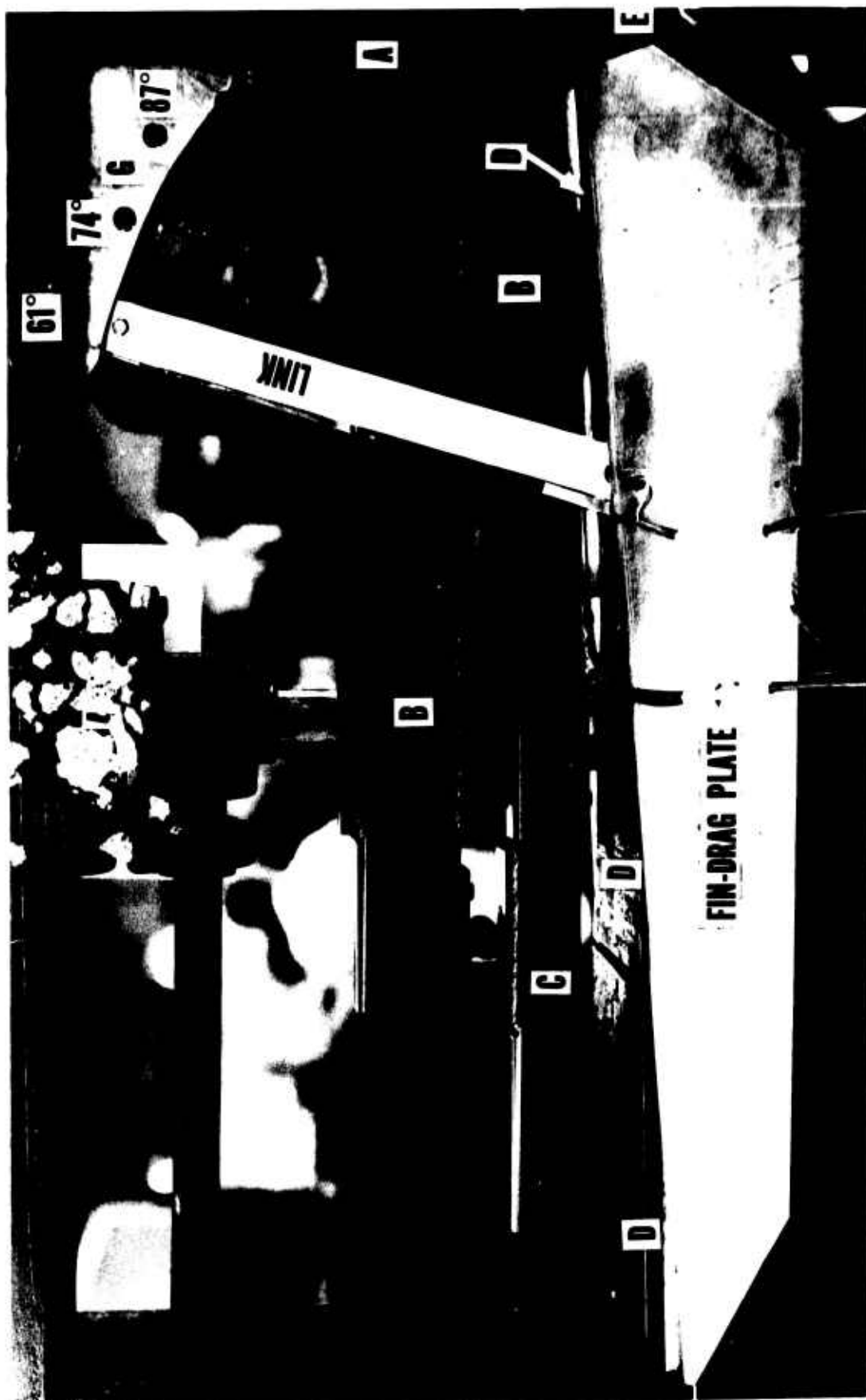
Figure 31   Test Set-Up of the Fin-Drag Plate

fin-drag plate through a 5/8 in. diameter pin. The objects of test 6 were:
(1) to cause failure and (2) to determine if the link support was necessary.

The results of the first four tests indicated that the analytically
determined stresses were conservatively high. Table IV presents results
obtained from Test 1. Test 5 resulted in no permanent deformation of any
structural component. The failure that occurred in test 6 consisted of
slight permanent bending of the 5/8 in. diameter link pin. The failure
could not cause impairment of the operation of the fin assembly. (Subsequent
flight testing indicated that the link supports were required--perhaps be-
cause of the pitchdown occurring on bomb ejection.)

4.2.2 Fin Assembly Tests

The second series of tests were performed to evaluate structural response
of the fin assembly at limit and ultimate loads. The fin-drag plate and the
energy absorber were omitted from the fin assembly for the tests. A view of
the test setup showing the assembled components installed in the loading fix-
ture, is given in Figure 32. The components shown are the support flange,
support tube, collar, link assemblies and clevis and a split tubular spacer
between collar and clevis; a different spacer was used for each fin opening
angle. The link orientation shown corresponds to a fin-drag plate opening
angle of 45 degrees. The test apparatus was designed to apply loads to the
link assembly and other components in a manner simulating that occurring
during various stages of fin-drag plate opening.

A series of two tests were conducted; each consisted of five different
fin-drag plate opening angles. Test 7 was conducted with loading applied to
impose limit load stresses in the link assembly for each angle. Test 8 was
conducted with ultimate load stresses imposed in the link assembly for each
angle.

The results of tests 7 and 8 are presented in Tables V and VI, respec-
tively. The stresses obtained for three representative fin-drag plate open-
ings are compared with calculated stresses. The tests were intended to
evaluate the fin assembly under limit and ultimate loads in the link assembly.
Since static testing methods were employed, limit and ultimate loads imposed
on the link assembly did not necessarily result in limit and ultimate loads
on other components of the fin assembly. The collar and link assemblies were
subjected to limit and ultimate loads as planned. The support tube and
support flange were under loaded in each test, but were subjected to loading
approximating their limit loads in test 8. The clevis was overloaded in each
case because of the absence of the dynamic centrifugal unloading force caused
by fin-drag plate opening.

It was concluded, from the fin assembly tests, that the entire fin
assembly proved structurally sound at limit loads and the link assembly,
collar, and clevis maintained their structural integrity at ultimate loads.
The results of both series of static tests indicated that the strength of
the MAU-91/B fin assembly was sufficient to withstand the anticipated loads.

4.3 Environmental Tests

A study was made of the various environmental conditions to which the
decelerator would be exposed during its life cycle. A total of eight

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TABLE IV. SUMMARY OF TEST RESULTS -- TEST 1

Gage No.	Description of Gage Location	Measured Stress psi	Average Measured psi	Corresponding Calculated Stress psi
11 ——— 12	Free edge of the unperforated fin	-17,400 ——— 3,220	7090	26,640
13 ——— 14	Free edge of the perforated fin	-14,550 ——— 4,890	4830	26,640
15	Crown	-20,270		-26,640
16	Bottom crease (unperforated fin)	24,730		32,960
17 ——— 18	Root of unperforated fin	5,660 ——— -13,150		not calculated
19	Bottom crease (perforated fin)	25,050		32,960
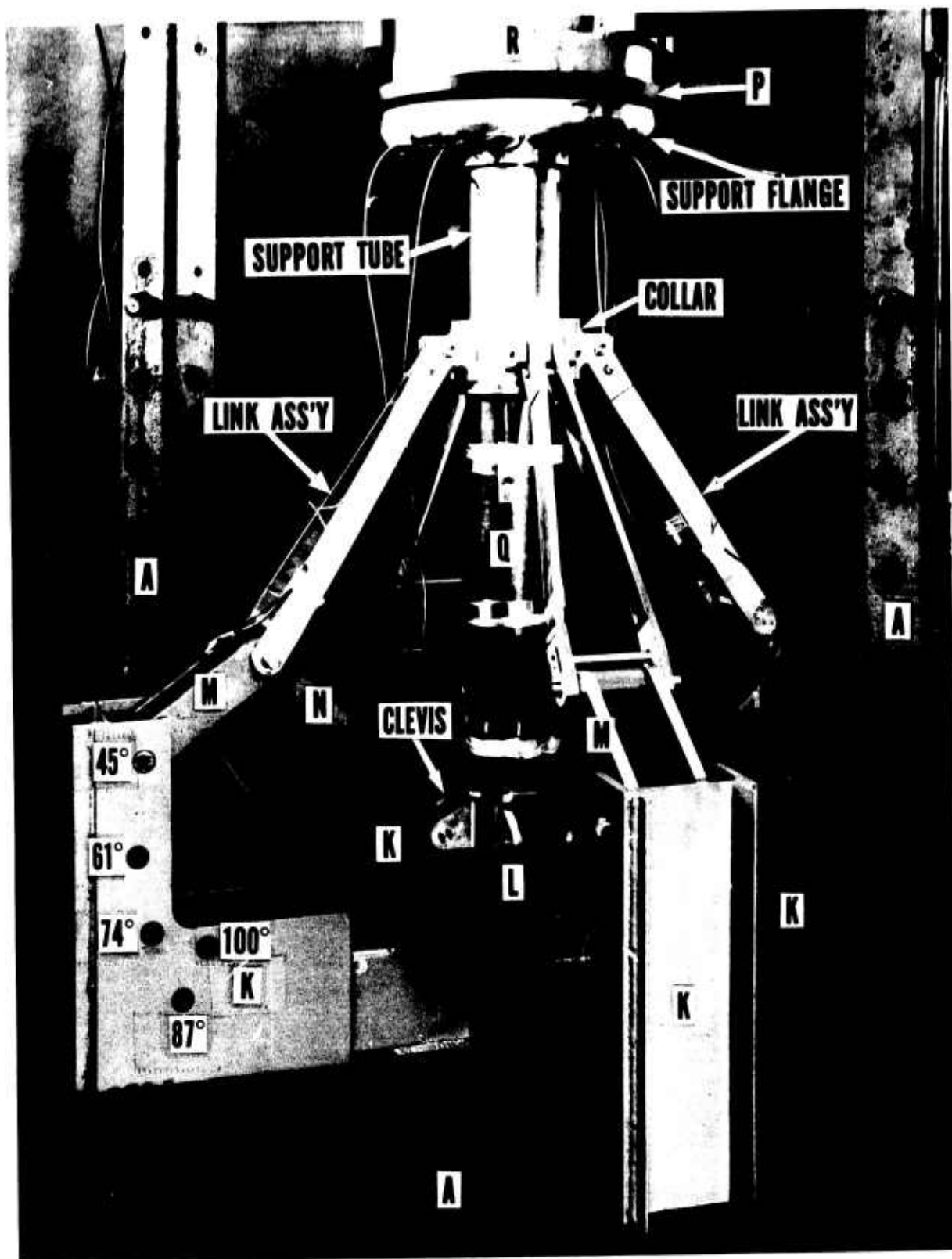
Figure 32 Test Set-Up of the Mod O Decelerator Assembly

TABLE V.   RESULTS OF TEST 7 LIMIT LOADS, MOD 0

Gage No.	PISTON FORCE = 34,950 lbs. α = 45°			33,180 lbs. α = 74°			38,300 lbs. α = 100°		
	Exp. psi	Avg. psi	Calc. psi	Exp. psi	Avg. psi	Calc. psi	Exp. psi	Avg. psi	Calc. psi
1	42,100			47,300			53,700		
2	46,000			45,300			40,600		
3	47,100			45,400			53,400		
4	50,900			47,000			46,200		
5	30,500		27,000	27,000		25,650	33,450		29,600
6	19,650			18,400			21.750		
7A	10,900 }	10,800	9,345	7,920 }	7,670	11,083	15,080 }	16,240	12,292
10	10,700 }			7,420 }			17,400 }		
7B	11,950		9,205	9,780		10,918	19,250		12,109
8	13,400 }	12,650	9,661	9,480 }	8,600	11,458	20,850 }	18,400	12,708
9	11,900 }			7,720 }			15,950 }		
20	10.700			9,580			11,020		
21	10,000	10,250	10,100	9,420	9,400	9,590	10,800	10,900	11,070
22	10,050			9,220			10,900		

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TABLE VI. RESULTS OF TEST 8 ULTIMATE LOADS, MOD 0

Gage No.	PISTON FORCE = 53,000 lbs. α = 45°			50,100 lbs. α = 74°			57,200 lbs. α = 100°		
	Exp. psi	Avg. psi	Calc. psi	Exp. psi	Avg. psi	Calc. psi	Exp. psi	Avg. psi	Calc. psi
1	71,000			68,700			75,000		
2	69,000			66,700			73,000		
3	72,000			69,000			75,200		
4	67,500			70,000			75,300		
5	45,800		40,970	44,000		38,730	48,700		44,760
6	29,850			28,750			31,720		
7A	15,550}	14,875	14,021	13,900}	13,380	16,624	25,100}	25,425	18,438
10	14,200}			12,860}			25,750}		
7B	16,060		13,813	14,930		16,377	26,700		18,163
8	16,380}	15,490	14,496	14,200}	13,175	17,187	28,500}	28,325	19,062
9	14,600}			12,150}			28,150}		
20	15,450			14,620			16,650		
21	14,250	15,110	15,320	14,620	14,380	14,480	16,380	16,130	16,730
22	14,630			13,900			15,350		

environmental parameters, and their influence upon decelerator integrity and behavior, were considered as follows:

1. High temperature
2. Low temperature
3. Temperature shock
4. High humidity
5. Salt fog
6. Sand and dust
7. Vibration
8. Shock

Analysis showed that the expected high and low temperature and temperature shock conditions would have little effect upon the performance of the decelerator because of its all metal construction and the lack of close tolerances for moving parts. Similarly, the high humidity condition was discounted because neither the decelerator nor any of its components could be adversely affected by prolonged exposure to moisture.

Sand and dust exposure was eliminated as a source of potential damage because of: (1) protection afforded to the fin assemblies during shipment and storage by the wooden shipping container, and (2) the lack of any moving parts which could be adversely affected by the presence of sand particles during decelerator deployment.

The rugged construction of the decelerator and the use of vibration proof fasteners throughout, ruled out the potential hazard to operation due to vibration and shock.

The one remaining environmental parameter which could exert a deteriorating influence upon decelerator behavior was salt fog. Salt fog exposure has the potential for causing physical damage through corrosion of painted or coated metal components because of chemical interaction. Consequently, a number of decelerator components were subjected to salt fog tests to uncover potential sources of trouble and (as part of the production quality assurance program) to evaluate production painting and coating processes.

4.3.1 Test Procedure

The salt fog tests were conducted in accordance with either Specification MIL-STD-810A, Method 509, Procedure 1 or Federal Specification QQ-P-416, for Class 2, type 2 specimens. The test specimens were supported within the salt spray chamber and subjected to salt spray tests for periods ranging from 48 to 200 hours. The chamber was so constructed that there was no direct impinging of the salt spray or dripping of the condensate on the units. An atomizer produced a finely divided, wet, dense fog, and the chamber was maintained at a temperature of 95°F.

The salt solution was prepared by dissolving 5 ± 1 parts by weight of fine flake salt in 95 parts by weight of de-ionized water. The salt solution consisted of sodium chloride containing less than 0.1 percent of sodium iodide and not greater than 0.2 percent of total impurities. The volume of salt spray solution collected within the exposure zone, was from 0.5 to 3.0 milliliters per hour for each 80 square centimeter of horizontal collecting

area. The specific gravity of the collected solution was between 1.023 and
1.036 and a pH between 6.5 and 7.2 measured at a temperature between 92° and
97°F.

At the conclusion of the tests the specimens were rinsed in running tap
water, air dried, and examined.

4.3.2 Test Results

A summary of all of the salt fog tests performed, pertinent data on the
specimens and test results is given in Table VII. Generally the test results
revealed little evidence of physical damage or corrosion to the test specimens.
In those samples which exhibited physical changes, the changes took the form
of slight or dark discolorations locally or over large areas. In one case,
two energy absorbers were penetrated by moisture with detrimental effects.

None of the changes noted as a result of the tests were considered
serious and it was judged that none would, in any way, compromise the per-
formance of the decelerators.

TABLE VII. RESULTS OF SALT FOG TESTS

Date Test Completed	Specimens No. & Type	Test Specification	Test Duration (Hrs)	Remarks
2/18/66	5 Fin-Drag Plates	MIL-STD-810A, Meth. 509, Proc. I	48	Slight discoloration in scratches (sample B-2). Discolorations on one side of fin (sample B-4).
3/14/66	2 Support Tubes	MIL-STD-810A, Meth. 509, Proc. I	48	
6/6/66	5 Flanges 1 Collar	MIL-STD-810A, Meth. 509, Proc. I	50	Slight change in color noted on surfaces of all specimens.
8/8/66	4 Energy Absorbers 1 Link Support 1 Support Flange 3 Fins	MIL-STD-810A, Meth. 509.1, Proc. I	200	Moisture penetrated into 2 energy absorbers.
1/3/67	2 Release Bands	QQ-P-416 Class 2 Type 2	96	Dark discolorations on both specimens.

SECTION V

CONTINUED DEVELOPMENT

Several additional decelerator design improvements were initiated on this development program. They include elimination of the collar, redesign of the support flange and links, elimination of the link support and redesign of the energy absorber. At the direction of the Air Force project engineer, work on the decelerator design improvements was stopped, and redirected instead to the development of the pyrotechnic and mechanical delay timers and, most important, improvement of the arming system. However, the decelerator improvement effort was continued under the Value Engineering Phase of the production contract, and the extent of such improved developments is described here.

5.1 Elimination of Collar (Mod 2 Design)

Adoption of the Mod 1 decelerator configuration, in which the pivot point for the fin-drag plates was changed from the rear to the front, made it possible to consider elimination of the collar. In Mod 0 it was essential to have a sliding collar, while in Mod 1 the collar became stationary. The collar in Mod 1 serves only to provide a stationary pivot point for the forward end of the links. If the pivot point can be provided by another component, then the collar may be eliminated. The Mod 2 design (Figures 33, 34, and 35) eliminates the collar by incorporating pivot points for the links in the support flange. A simple spacer replaces the collar on the support tube to maintain the spacing of the remainder of the fin assembly components, so that, with the exception of the links, all other Mod 1 components may be used in the Mod 2 concept.

In the Mod 2 concept, the forward pivot for the links is 2-1/4 inches forward of its corresponding Mod 1 location. Accordingly, the Mod 2 links are 2-1/4 inches longer than before. Because of the increased link length and the farther forward location of the link pivot point, the maximum link angle (angle between link and axis of fin assembly) will be reduced from 46 to 42.5 degrees. The smaller maximum link angle will reduce the load which must be carried by the link.

A stress analysis shows that the maximum link tension will be reduced from 22,700 pounds to 19,800 pounds. The reduced link tension would permit fabrication of the longer Mod 2 links from 6061-T6 or 6070-T6 aluminum alloy instead of the more costly 7075-T6 aluminum used for the Mod 1 links. Furthermore, no link failure of any kind has ever occurred in any of the tests performed on fin assemblies, indicating that the margin of safety of the present links is greater than necessary.

The Mod 1 support tube was designed originally for the Mod 0 configuration with its greater load condition. When the Mod 1 concept was adopted, the support tube design remained unchanged. In the Mod 2 configuration loading is reduced further by eliminating the tension load from the links. For this reason, the Mod 2 support tube can be fabricated from 6061-T6 or 6070-T6 aluminum alloy instead of 7075-T6.

FIN-DRAG PLATE

SUPPORT TUBE

CLEVIS, INITIAL POSITION

CLEVIS, DISPLACED POSITION

LINK SUPPORT

LINK

SPACER

MODIFIED SUPPORT FLANGE

LINK PIVOT POINT
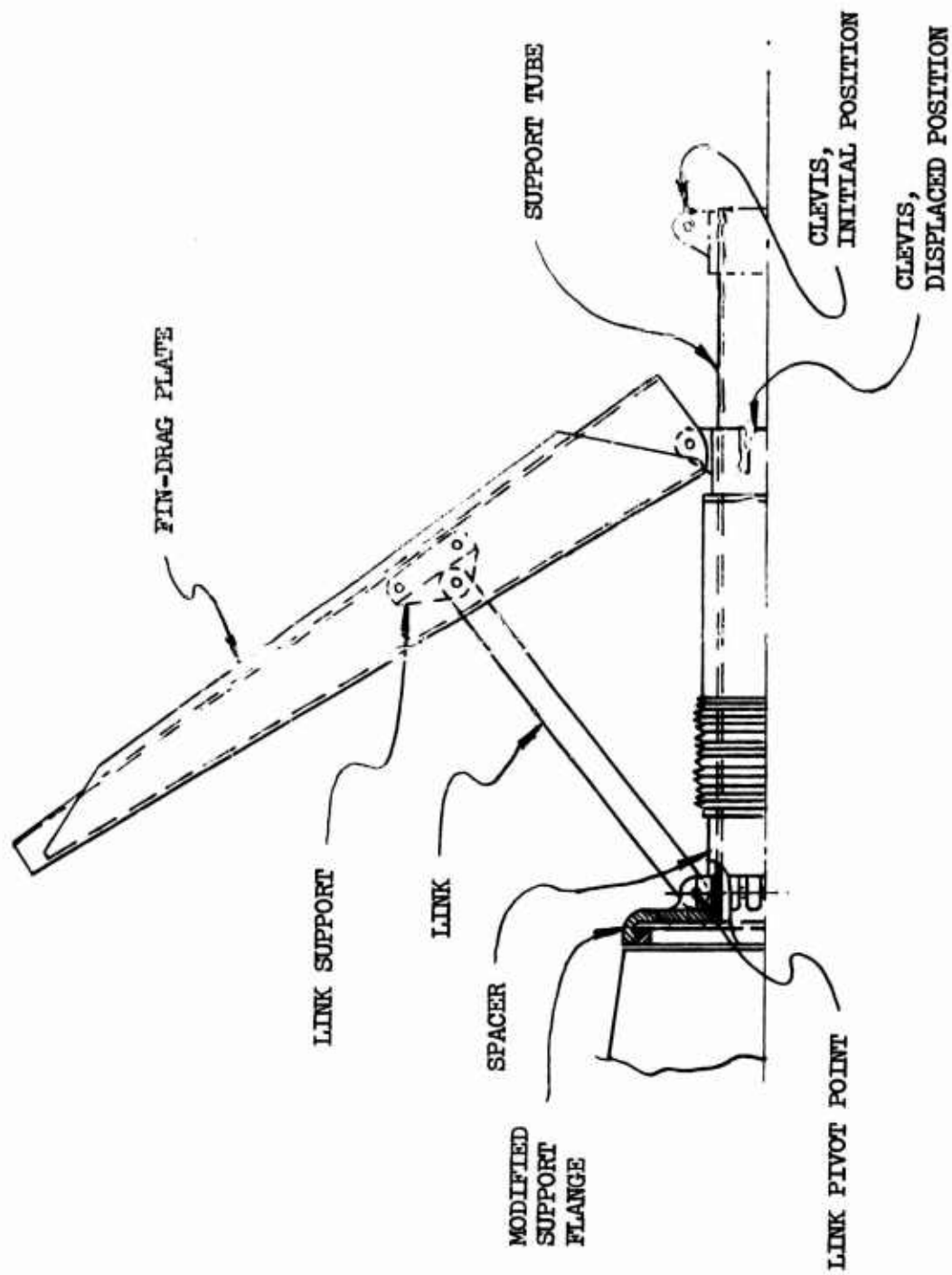
Figure 33 Mod 2 Fin Assembly Concept

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Fin Drag Plate

Area of fin which opposes opening
force during deployment

Clevis, displaced position

Energy Absorber

Link

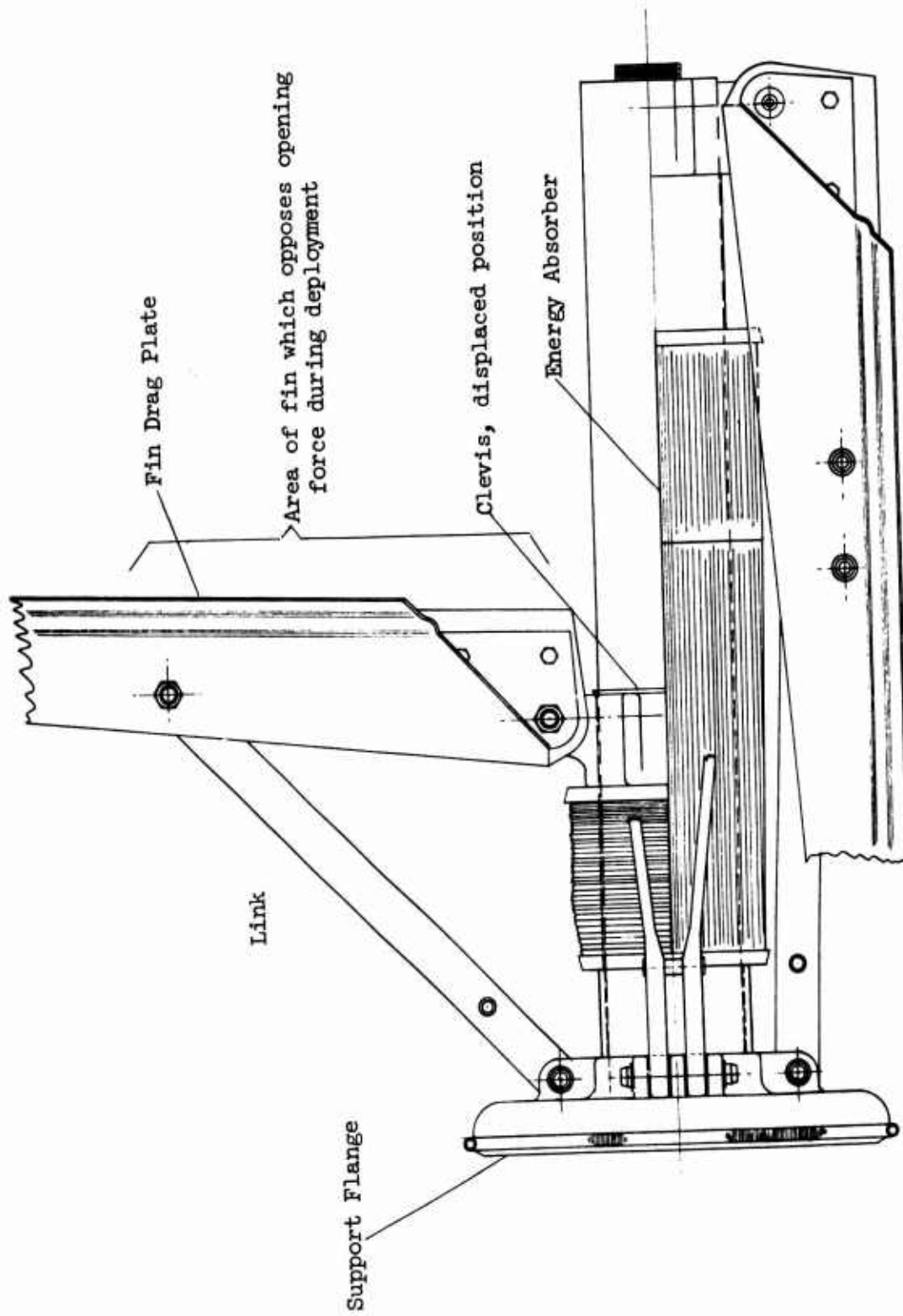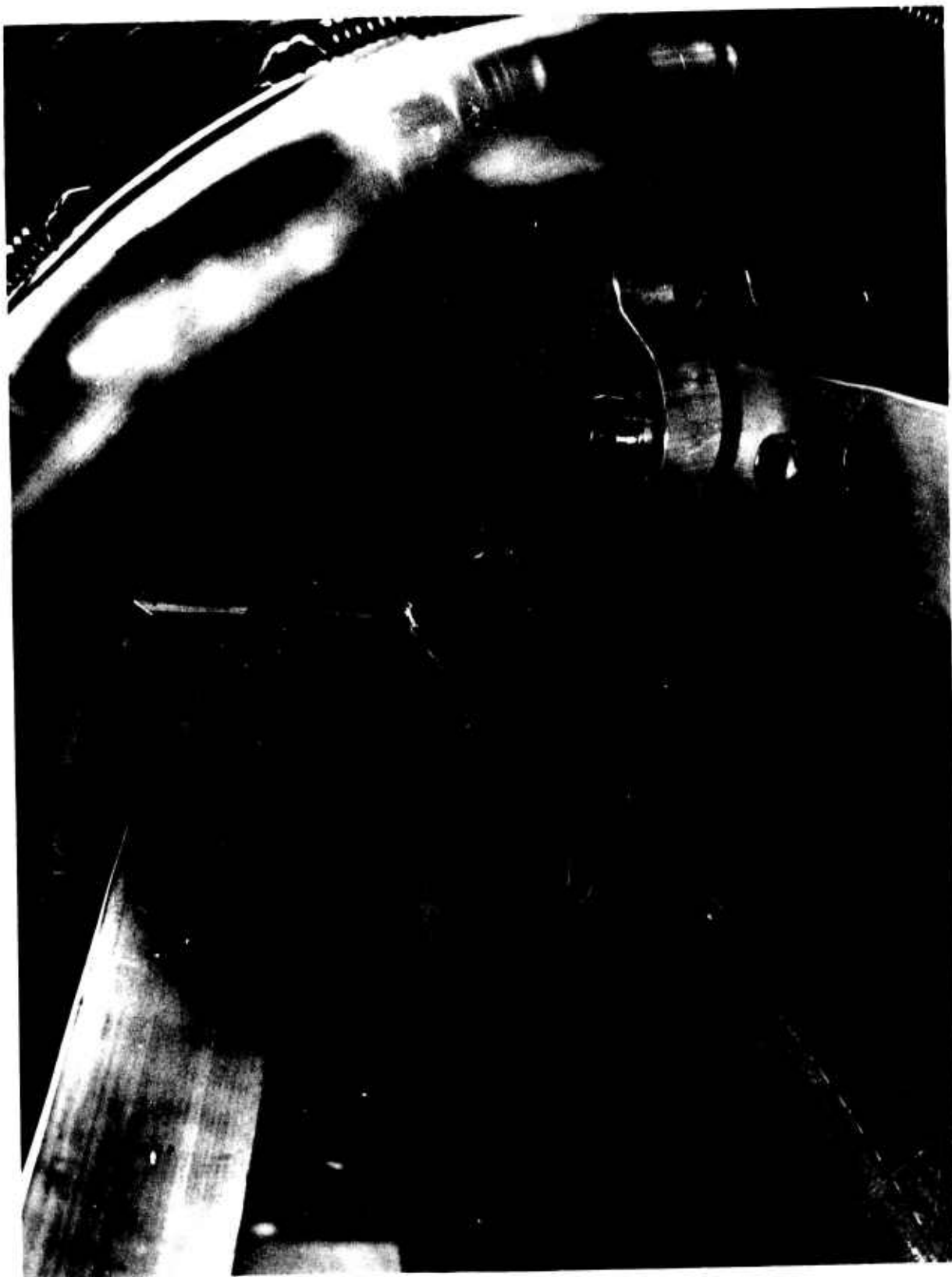Support Flange

Figure 34   Mod 2 Fin Assembly

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Figure 35 Support Flange for Mod 2 Fin Assembly

5.2 Design Improvement Program

5.2.1 Computer Studies

While MOD 1 was a major design improvement over MOD 0, and MOD 2 was a significant design improvement over MOD 1, both designs had geometric limitations because they used components from the MOD 0 concept. While use of MOD 0 components did not compromise the MOD 1 and MOD 2 designs unduly, the possibility did exist that a more effective retarder design, based on the reverse opening concept, might be achieved. The stress analysis work showed that the loads on the various components are directly affected by the geometry of the link mechanism. The important dimensions are A, B and C illustrated in Figure 36. The total energy input to the system, which must be taken out by the energy absorber, is strongly affected by the link-to-fin attachment point (dimension A, Figure 36). Therefore, it would seem that the minimum loading could be achieved by making dimension A as large as possible; however, this is true only within certain limits because as A becomes larger the link length (dimension B) becomes smaller, the angle D becomes larger for each corresponding fin opening angle, and the load imposed on the link and flange begin to increase.

The fin-drag plate and the support tube dimensions are fixed by the total bomb/retarder envelope. The optimum configuration is then obtained by varying the parameters A, B and C to minimize the load in the components. GARD developed a computer program which enabled us to determine the component loads as these parameters are varied. With this program, we were able to optimize the retarder geometry within the constraints imposed by the bomb/ retarder envelope, and some compromise in the idealized dimensions was required.

5.2.2 MOD 3 Design

The MOD 3 design is a further improvement over the MOD 2, and utilizes the results of the computer studies. While some compromise had to be made in the link-fin attachment point and the length of the link, MOD 3 represents a near optimum retarder design. The MOD 3 design is shown in Figures 37 through 40. The fin-drag plate, the clevis, and the support tube remain the same as in the MOD 1. The primary changes in the MOD 3 design are:

(1) The support flange has been revised (see Figure 38) by moving the link attachment points out to the extreme edge of the flange and spreading them apart so that the links can be straight. The flange was redesigned to obtain its stiffness from webs rather than material thickness.

(2) The links (see Figure 39) are straight, have been made thinner but higher to get the required cross-section areas, and are designed to be extruded from 6061-T6 or equivalent material. The link assembly has been changed, the spacers have been removed and the links are assembled individually to the retarder. A single spacer is used, and consists of a sleeve placed over the link-fin attachment pin.
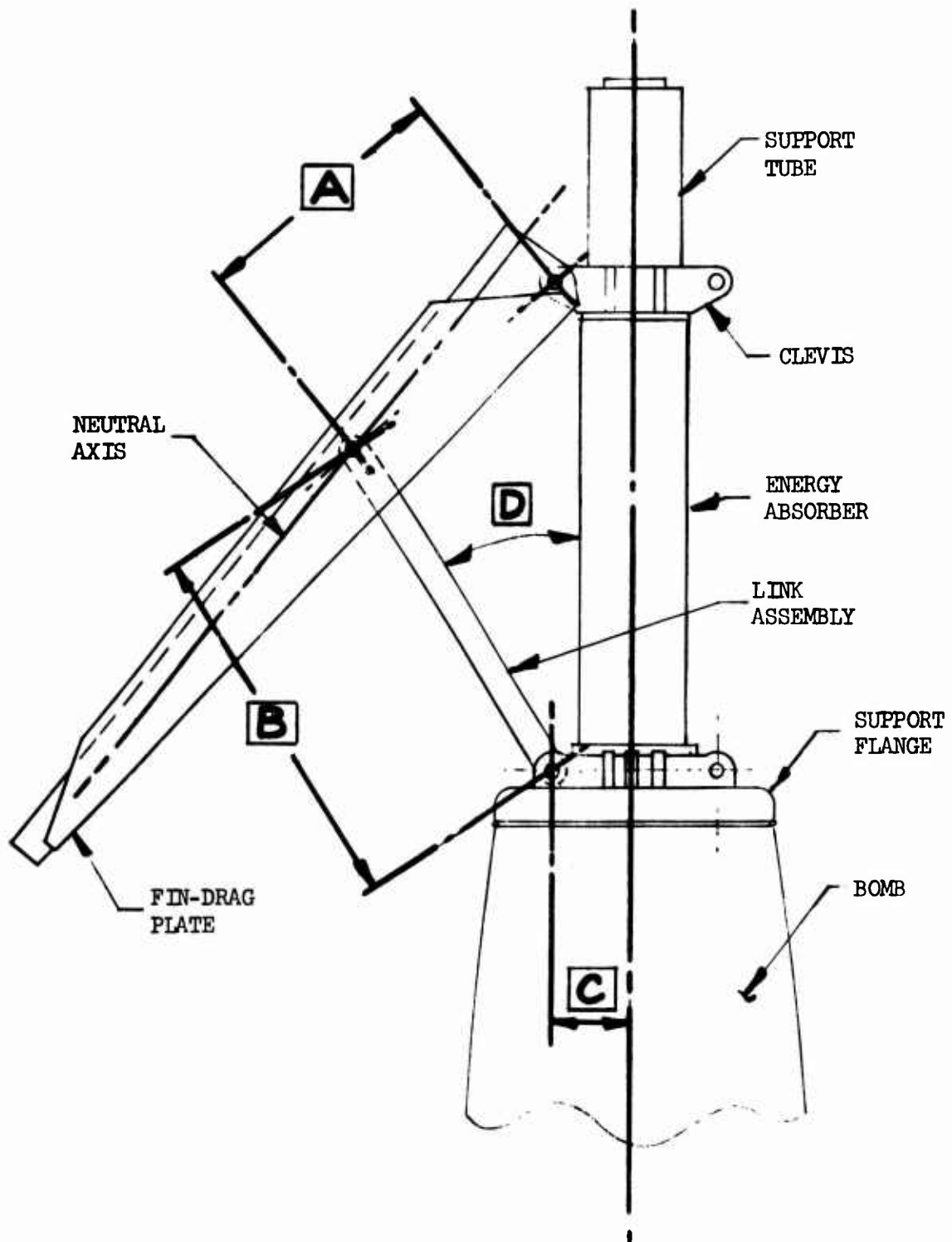
61

Figure 36   Retarder Dimensions Considered in Optimization Studies
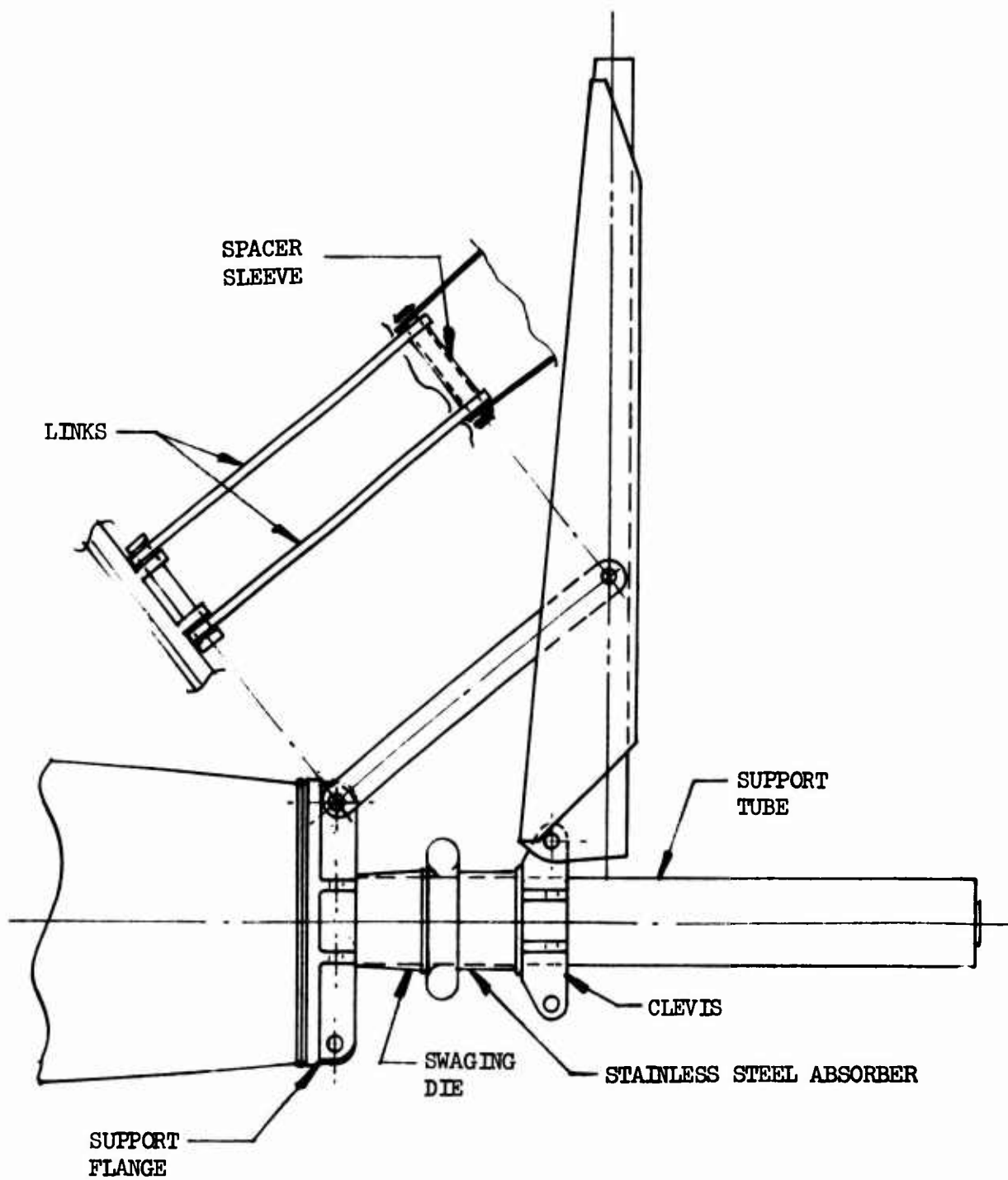
Figure 37 Mod 3 Version of MAU-91A/B
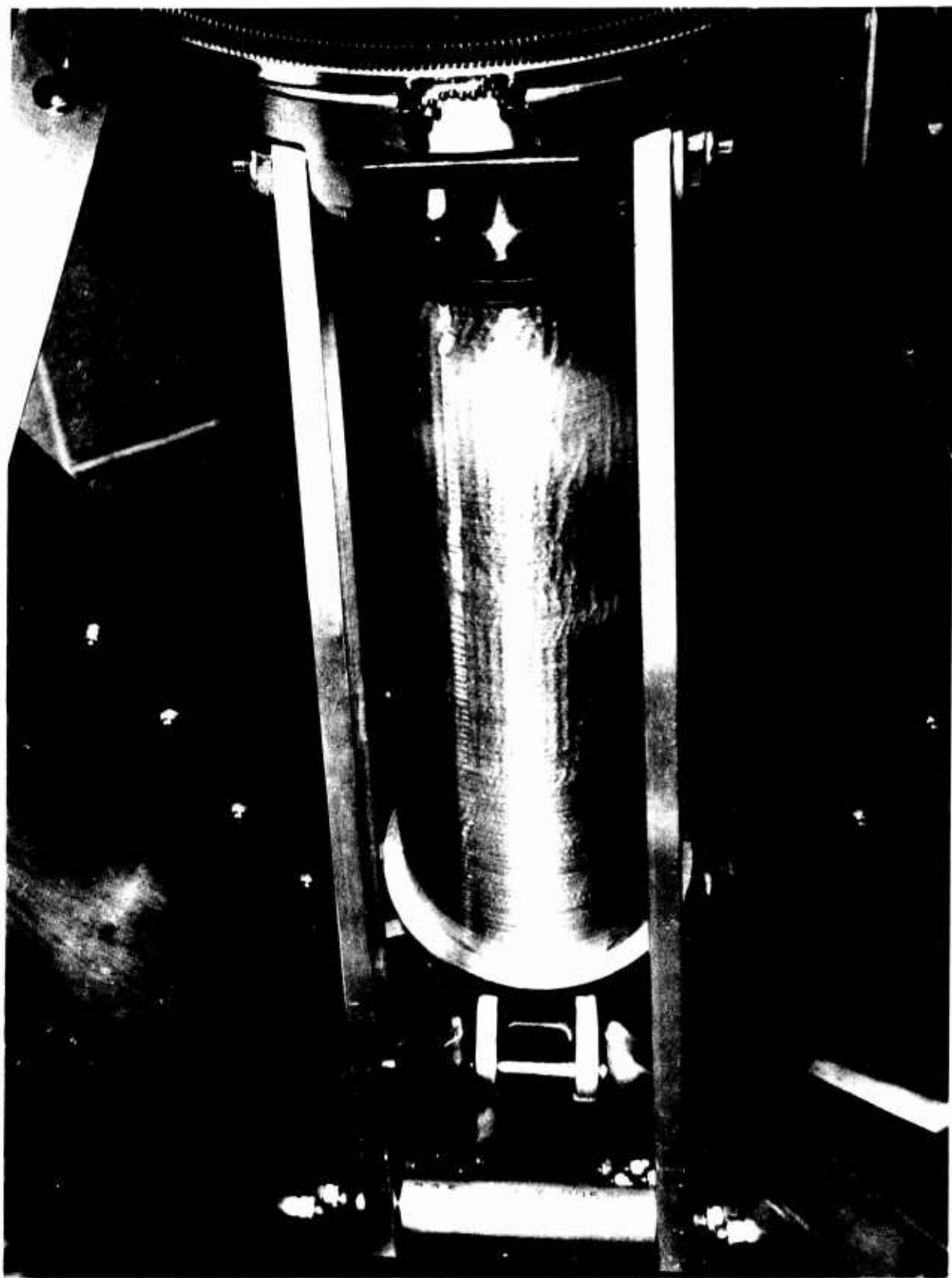
Figure 38   Mod 3 Support Flange
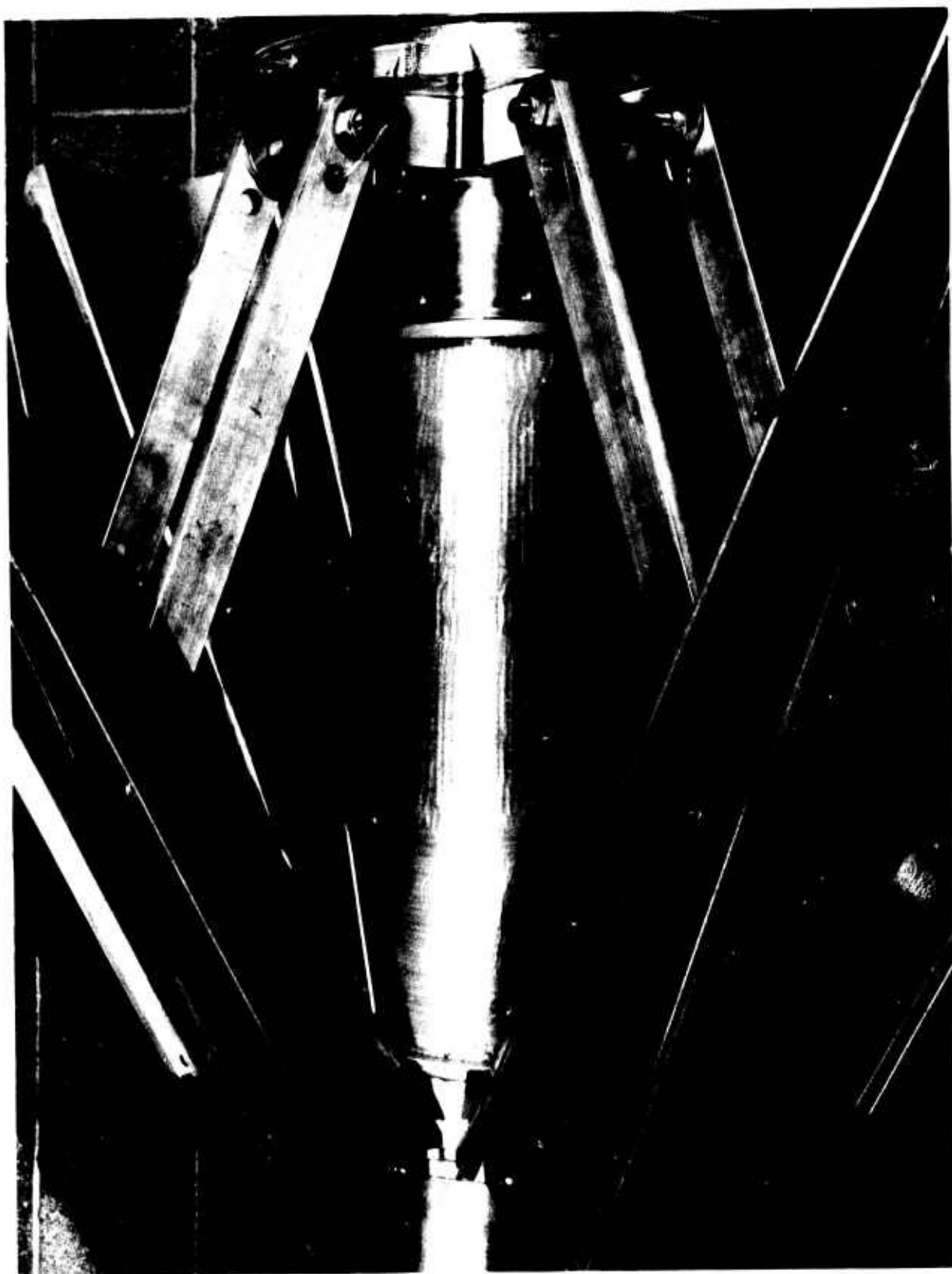
Figure 39   Mod 3 Links

Figure 40   Mod 3 Fin Assembly

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(3) A larger link-to-fin pin is used and the link support has been deleted. The attachment is made by a single pin located on the neutral axis of the fin-drag plate (see Figures 39 and 40).

(4) The retarder can use an energy absorber with a longer stroke and is designed to take either the standard honeycomb, or the stainless steel, split tube, absorber.

A number of MOD 3 units were fabricated for static test and for airdrops. Static tests were conducted and all components performed satisfactorily; however, the airdrops were not made. The primary advantages of the MOD 3 design are the straight links which can utilize extruded bar stock, and perhaps have the ends shaped with a blanking die. And the other is the deletion of the link supports in the fin-link attachment. Deletion of the link supports is made possible by placing a larger diameter single pin on the neutral axis of the fin-drag plate, and taking advantage of the smaller load transmitted because of the reduced linkage angle.

5.2.3 Energy Absorber Investigation

The results of the preliminary investigation on developing a steel absorber for use on the MAU-91/B fin assembly indicated that the use of a steel tube and swaging die is a promising approach. In the improvement portion of the program we continued these investigations in order to develop a lower cost, more versatile energy absorber. The steel tube absorber has two significant advantages in this application. The first is that the stroke of the steel absorber can be made longer without increasing the "solid" length. That is, the honeycomb will give approximately two inches of additional stroke for every three inches of additional length, since one inch of the additional length becomes solid length after crushing. For practical purposes, the steel absorber's solid length is independent of the total stroke and depends only on the length of the swaging die and the size of the coil. The second advantage is, that in the MAU-91/B, the steel absorber can also replace the steel sleeve which is put between the clevis and the support tube to prevent cocking of the clevis during opening.

As the development continued, we arrived at stainless steel, welded tube, with a preformed end and notched to provide the desired number of coils. As the swaging die developed, we discarded the use of knives and went from a steel swaging die to a 6061-T6 aluminum die. The development looked so promising that we fabricated two stainless steel absorbers, based on this principle, installed them in MAU-91/B fin assemblies and airdropped them. Two drops were made, one at 600 knots and one at 450 knots. Both were successful (see Figures 41 and 42), and were within 6% of the predicted stroke.

The stainless steel absorber tube, using a swaging-curling die, offers a very promising type of energy absorber. It offers great versatility with respect to length of stroke and force level; it has inherent corrosion resistance, long shelf-life, and is unaffected by its operating environment.

5.3 Trajectory Studies

The success of the retarder depends upon its ability to provide adequate separation between the aircraft and the bomb at bomb impact. The separation

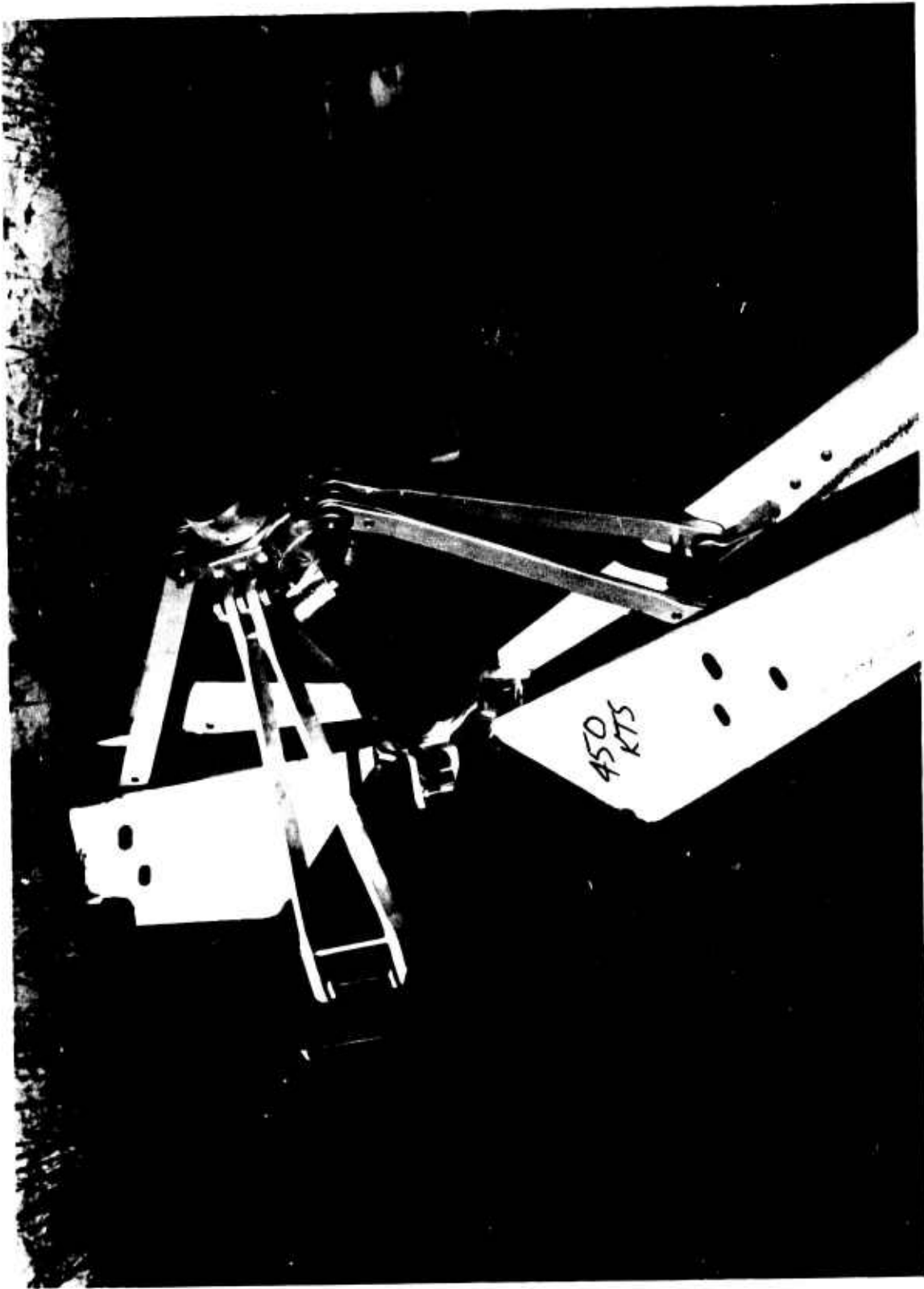Figure 41 MAU-91/B With S/S Absorber After Drop at 600 Knots

Figure 42 MAU-91/B With S/S Absorber After Drop at 450 Knots

distance achieved is dependent upon the speed and altitude of the aircraft at bomb release, and the ballistic characteristics of the bomb. Trajectory studies were performed to determine separation distance for various flight conditions, and a summary of the predicted trajectories is given in Figure 43.

Since no wind tunnel tests were conducted, the coefficient of drag, C_D, of the bomb/fin combination was determined from actual trajectory data. Using a computer program developed for predicting trajectories of the bomb/ fin combination, a curve of C_D versus Mach number was derived (Figure 44). The C_D values were then substituted back into the computer program and the predicted trajectory was compared with the flight test trajectories. The results were very good, and the predicted trajectories, using the computed C_D, matched the actual trajectories very closely. The C_D derived from the flight test data, should be more accurate than the estimate used in the design calculations and could be used in further design work.
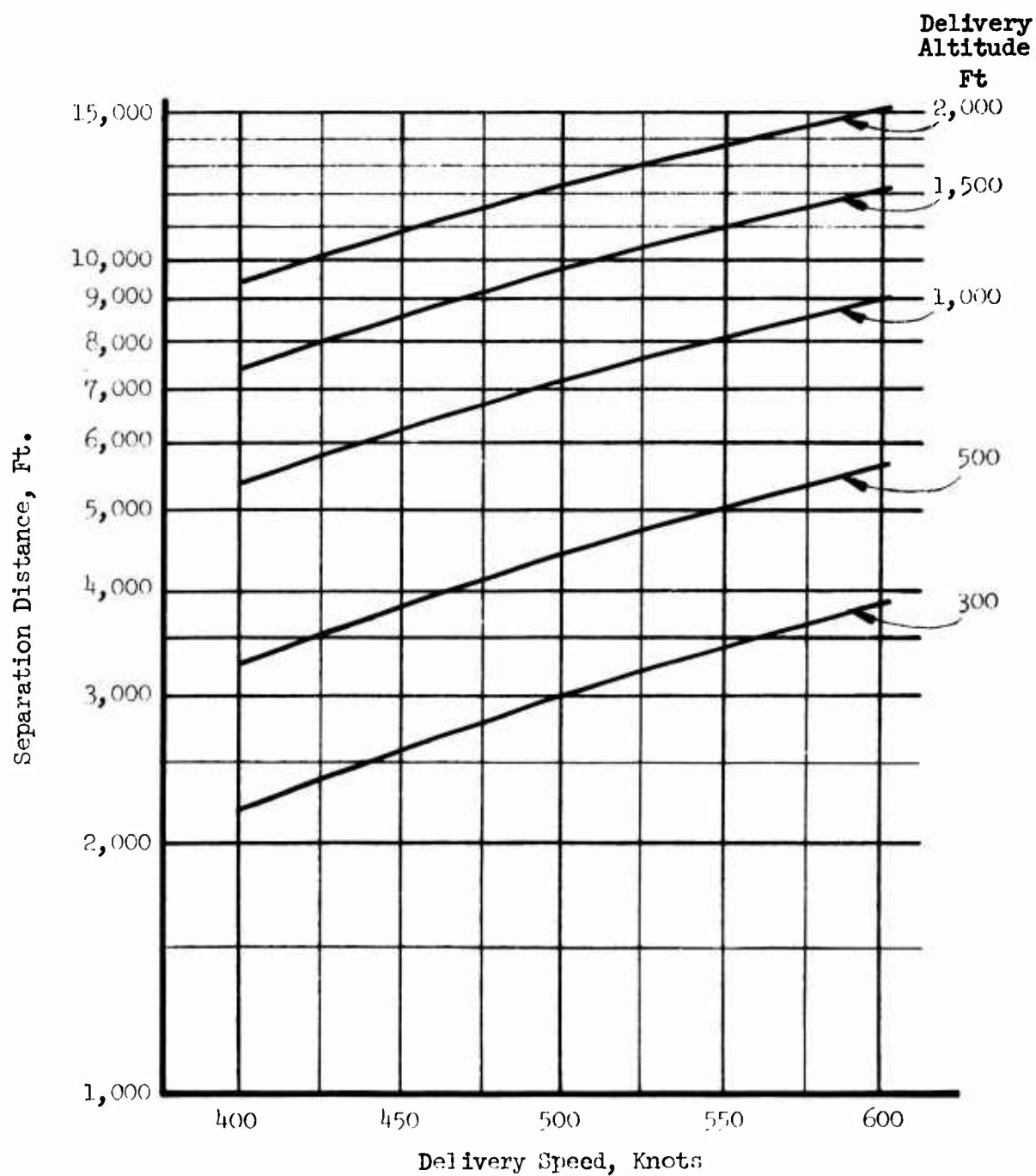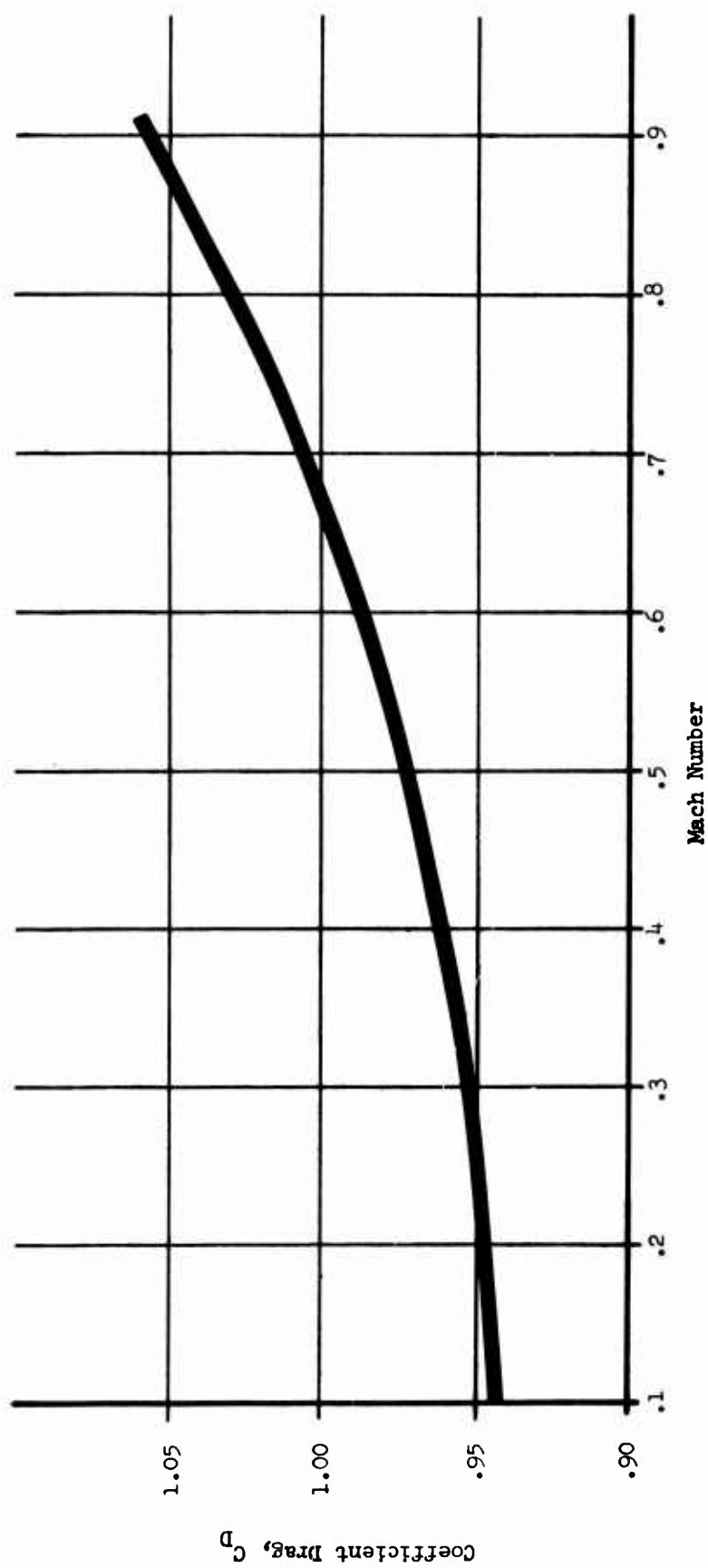
Figure 43   Summary of MAU-91/B Trajectories

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Figure 44 Coefficient of Drag Vs. Mach Number MAU-91/B Flight Test Data

SECTION VI

PACKAGING DEVELOPMENT

Packaging was required for overseas shipment of the MAU-91/B Fin Assembly. Initial packaging investigations were directed toward both single pack and multiple pack designs. The eventual package developed was a multiple pack containing four fin assemblies, featuring wirewound, wooden crate, construction utilizing plywood panels, plywood inserts and a built-in skid.

6.1 Preliminary Packaging Designs and Testing

The preliminary package design investigations were based on a single unit package and a multiple (four) unit package. The first single unit design developed was a package fabricated entirely from plastic foam material. It is shown in Figure 45. The package was given a preliminary evaluation test in accordance with Federal Test Method Standard 101a. The preliminary tests indicated that the unit could meet the requirements. However, the foam plastic outer casing was found to be less resistant to puncture than a wooden crate.

The results of the evaluation of the all foam plastic package led to the design of a package which utilized foam plastic inserts, for cushioning and positioning the fin assembly and its accessories, and a plywood wrap-around crate for the external covering. The package is shown in Figure 46. The package was estimated to afford excellent shock-absorption capability for protection of the fin assembly and to be very resistant to puncture and dropping.

Discussions were held with personnel at Ogden Air Material Area, (OOAMA) Hill AFB, Utah, who had directed the shipping container design for the Mark 15 fin assemblies. The most desirable packaging, according to OOAMA personnel, would be a multiple pack. Consequently, it was decided and agreed upon mutually by ATWD, GARD and OOAMA that an optimum pack would contain four fin assemblies. It was emphasized by OOAMA that the users in the field had a capability for lifting up to 2,000 pounds in a single pallet, and the estimated weight of a four pack unit was placed at 600 to 700 pounds gross. Thus, a four pack unit could be conveniently handled. Further, a built-in skid was extremely desirable, and OOAMA had good success in the past with wooden crating utilizing plywood panels.

A multiple (four) unit pack, based upon the single unit package shown in Figure 46, was also designed. The package utilized foam plastic inserts for positioning the fin assemblies and holding their accessories, a wire-bound plywood exterior, and a permanently attached skid. This package is shown in Figure 47.

An additional design for a multiple unit pack was developed, the package consisted of a plywood exterior and plywood end caps used internally to position and hold the fin assemblies and the accessories. The design, also for a four unit package, is shown in Figure 48. The use of plywood inserts instead of plastic foam inserts was proposed to reduce cost of the package. A shipping container conforming to this design and containing four fin assemblies, was tested in accordance with Federal Test Method Standard 101a and the

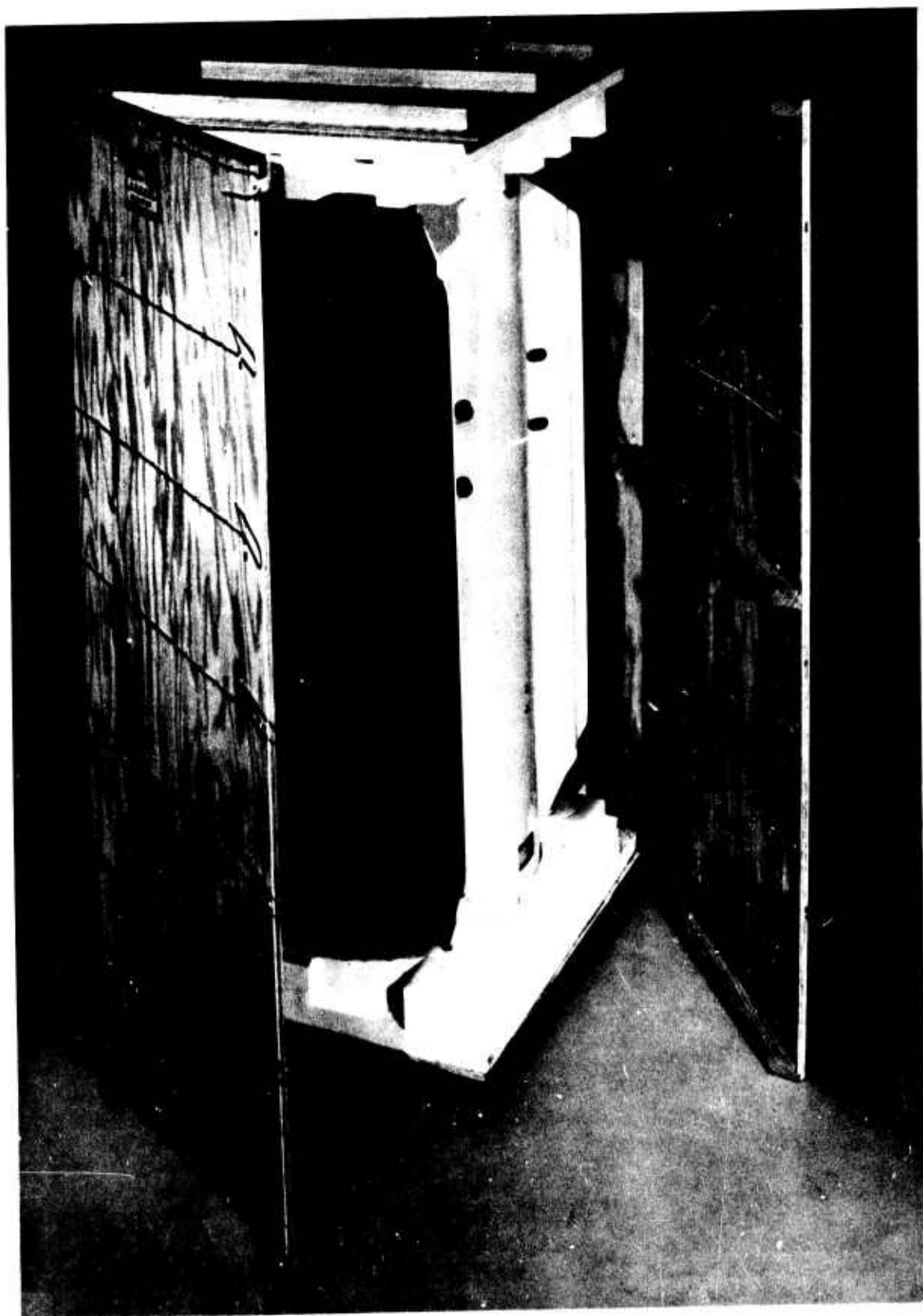Figure 45 Single Unit, All Foam Package

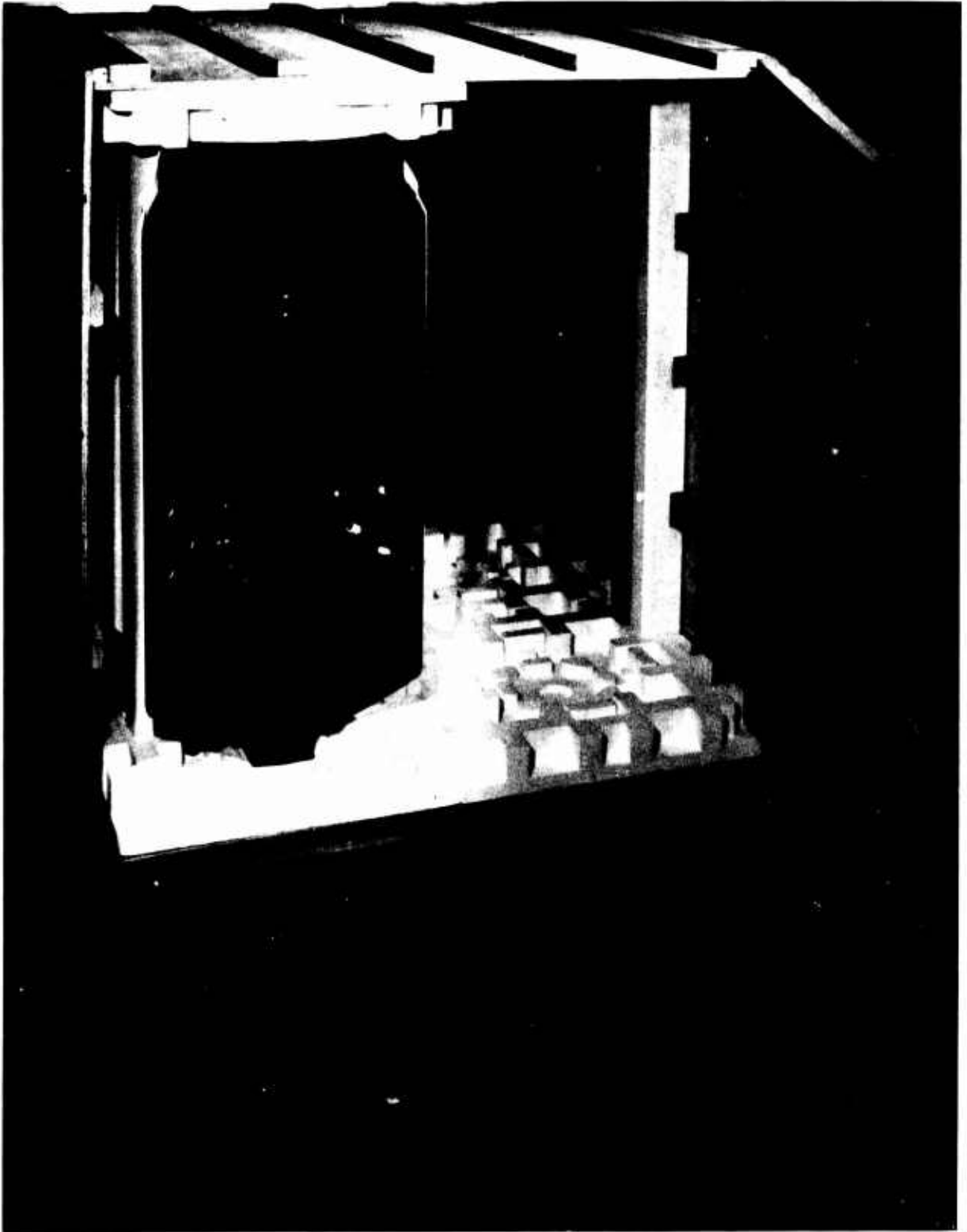Figure 46 Single Unit, Foam and Plywood Wrap-Around

Figure 47   Multiple 4-Unit Package
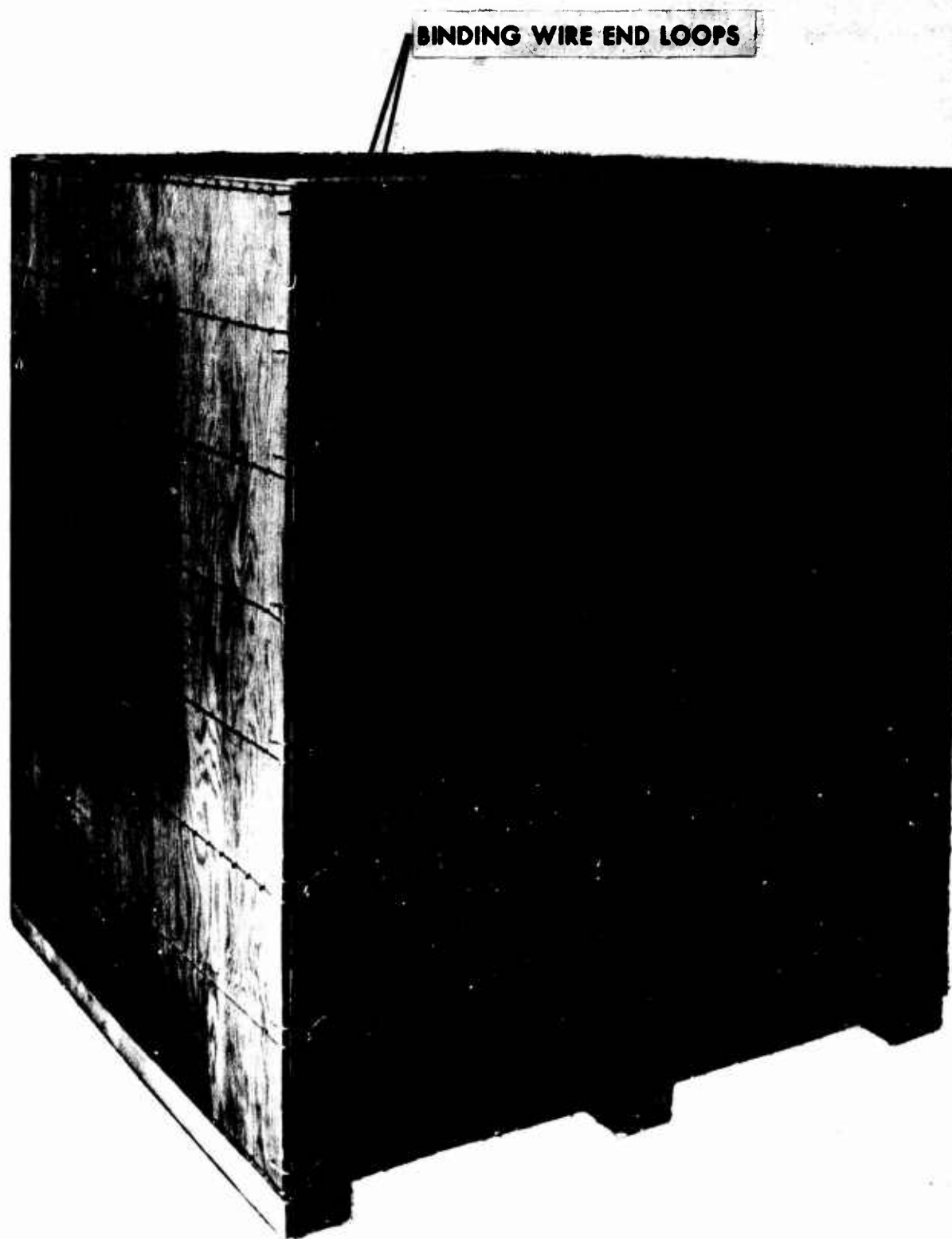
BINDING WIRE END LOOPS

Figure 48 Plywood 4-Unit Package

package passed the test satisfactorily. A copy of the test report was submitted to ATWB upon completion of the testing and the shipping container was recommended for packaging of the MAU-91/B fin assemblies.

6.2 Final Packaging Design

The final package design for shipment of the MAU-91/B fin assemblies was based upon the multiple (four) unit pack concept utilizing a wirebound, plywood exterior construction, plywood end caps for positioning of the fin assemblies and accessories, and a built-in skid. The final package design is shown in Figure 49, and the approximate overall size of the final package design is 48 in. high by 40 in. by 40 in. The original skids permitted two-way entry. With the addition of nine pieces of thick hardwood blocking at the corners, center and center of each side, and three hardwood runners, four-way entry was permitted. The sides are wirebound, and 3/4 inches by .023 inch thick steel strapping is used in addition to staples for closing the assembly after packing the contents.

Four pieces of chemically inert, moisture resistant paper are placed on the base with one each directly under each fin assembly to prevent direct contact of the fin assemblies with the wooden insert and package structure. A .006 in. thick polyethylene sheet is used as a moisture barrier on the inside of the top to cover all four of the fin assemblies and protect them against direct intrusion of rain water, etc. The container with side panels removed is shown in Figure 50.

In addition to the four fin assemblies contained in each crate, the package contains eight GFE bomb suspension lugs, one spare garter spring assembly and one spare locking pin assembly as shown in Figure 51.

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Figure 51 Components Stapled to Base of Shipping Container

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The program was successful, and achieved all of the original, and additional, objectives. The original design concept, essentially that of scaling up the MARK 15 fin assembly, because of the weight limitations and the delivery speeds, was not a feasible approach. This required a more extensive design program and the development of a new basic retarder concept. The prototype retarders were successfully deployed at the 600 knot design speed from those aircraft stations which gave the bomb/fin combination a level ejection. However, the majority of aircraft stations imposed a severe pitchdown on the bomb/fin combination, at ejection, which imposed extremely severe loads on the retarder components. This pitchdown caused a number of fin failures and resulted in an additional design innovation--the reverse opening technique. The reverse opening technique was achieved utilizing the original prototype components with only minor modifications. The reverse opening technique was achieved utilizing the original prototype components with only minor modifications. The reverse opening technique was designated the MOD 1 fin, and was the version placed into production.

Additional design studies resulted in improved retarder designs, which gave stronger units with a lower cost production potential. In addition, these studies resulted in the development of a satisfactory alternate technique for absorbing energy generated by the opening forces. This technique utilizes a tube forced over a swaging and curling die. This absorber was, also, successfully airdropped.

During the program, a requirement for dropping the M117 retarder bomb from a B52 aircraft developed. The large height of the B52 bomb bay required a different release technique. The initial approach utilized a pyrotechnic, time delay device which enabled the bomb to fall free of the aircraft prior to deployment of the fins. However, the tolerance inherent in a pyrotechnic delay was not suitable for this type of bombing. Further development resulted in the mechanical delay, which consists of a 17 foot, stainless steel lanyard, packaged in a wrap-around belt. This delay device was successful, and is being further tested by the Air Force.

7.2 Recommendations

Additional effort could be devoted to further improving the retarder design, and in achieving an item which could be produced at a lower cost.

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ASD (ASZSP)	1	PICATINNY ARSENAL (SMUPA-DWS)	1
ASD (ASNNS)	1	PICATINNY ARSENAL (AMSMU-SS-SC)	1
ASD (ASZBE)	1	AFSC STLO (SCTL-15)	1
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC	Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida

13. ABSTRACT

This program was concerned with the design, development, fabrication and testing of a prototype speed brake decelerator that gives the M117, 750 pound bomb a low level delivery capability. The requirements for the decelerator became urgent, as a result of the conflict in Southeast Asia, and the program was expanded to include development of preliminary production tooling and fabrication of production type decelerators to qualify the unit for aircraft. The decelerator was designated the MAU-91/B Fin Assembly and was put into production by GARD concurrent with this research and development program.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Speed brake decelerator						
Low level delivery						
Delayed opening device						
Guide assembly						
Fin assembly						